WATER-SUPPLY POTENTIAL OF THE FLORIDAN AQUIFER IN OSCEOLA, EASTERN ORANGE, AND SOUTHWESTERN BREVARD COUNTIES, FLORIDA

By Michael Planert and Walter R. Aucott

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ABBREVIATIONS, CONVERSION FACTORS, AND GEODETIC DATUM

For use of readers who prefer to use metric units, conversion factors for terms used in this report are listed below:

Multiply	By	To obtain
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (m^2)	2.59	square kilometer (km^2)
gallon (gal)	3.785	liter (L)
cubic foot per second (ft^3/s)	28.32	cubic decimeter per second (dm^3/s)
gallon per minute (gal/min)	0.0630	liter per second (L/s)
million gallons per day (Mgal/d)	0.0438	cubic meter per second (m^3/s)
gallon per minute per foot [(gal/min)/ft]	0.2070	liter per second per meter [(L/s)/m]
foot per day (ft/d)	0.3048	meter per day (m/d)
square foot per day (ft^2/d)	0.09290	square meter per day (m^2/d)

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ABSTRACT

The city of Melbourne and adjacent areas in south Brevard County obtain their water supply from Lake Washington. In 1982, the lake could provide a maximum of 15 million gallons per day, but the projected need for the year 2000 is nearly three times that amount. As one alternative for a future water supply, this study investigated, with a digital model, the potential yields of well fields completed in the Floridan aquifer. Poor quality of water precluded locating a well field within Brevard County. The most advantageous area for development was in central Osceola County.

Lithologic and geophysical logs were used to define hydrologic units. The units consist of (1) a surficial aquifer of unconsolidated sand, shell, and clay that contains the water table underlain by (2) a confining layer composed mainly of clay and silty sand which overlies (3) the Floridan aquifer. The potential location of a new well field was based on obtaining a water supply with chloride concentrations below 250 milligrams per liter.

Seven pumping schemes were simulated with the digital model. Each simulation was made under steady-state conditions so that storage properties of the ground-water system were not included. To evaluate the success of a particular scheme, the potentiometric surface is used to define the area of diversion from the pumping centers after a new equilibrium is reached. The area of diversion is plotted on a map of chloride concentrations, and by comparing how much of the area has overlapped into the zones of poorer water quality, evaluation of the particular schemes can be made. This accounts for lateral intrusion of poorer quality water only; data are insufficient to analyze water-quality problems from upconing of poorer quality water.

Four pumping schemes included a combination of pumping from a hypothetical well field in Osceola County and increasing pumpage rates of the Cocoa well field in Orange County which supplies the city of Cocoa in northern Brevard County. One scheme evaluated increasing pumpage in the Cocoa well field only. Two schemes evaluated an area in the southwest corner of Brevard County where chloride concentrations are less than 250 milligrams per liter.

The Osceola-Orange County pumping schemes should produce water of suitable quality. The schemes produced quantities that ranged from 28 to 65 million gallons per day. Only the scheme that produced 65 million

gallons per day intercepted a zone of water with chloride concentrations greater than 250 milligrams per liter, but the percentage of the zone within the area of diversion was small.

The water-supply potential for the southwest corner of Brevard County is about 5 million gallons per day. A scheme that would produce 20 million gallons per day intercepted a large zone of poor water quality, and it is doubtful that this scheme would succeed.

If the ground-water alternative is chosen for the future supply, it would be desirable to install an observation well network to monitor head changes, chloride concentration trends east of the pumping centers, and chloride concentration trends in zones below the pumped zone.

INTRODUCTION

The Floridan aquifer (limestone and dolomite) is the primary source of water supply for east-central Florida. In most of Brevard County though, the Floridan aquifer contains water with chloride concentrations that exceed the recommended limit of 250 milligrams per liter (mg/L) for public supplies (U.S. Environmental Protection Agency, 1977, p. 17146). Therefore, much of Brevard County has difficulty in obtaining acceptable public water supplies. Small amounts of ground water are available from shallower aquifers, but the quantity is not sufficient for large public supply. The source of water for south Brevard County is Lake Washington (fig. 1) which supplies the city of Melbourne and adjacent areas. The lake water is subject to periodic algae blooms, and seasonal increases in chloride concentrations have exceeded 200 mg/L. Most of Brevard County is a discharge area where the potentiometric surface of the Floridan aquifer is above land surface, and there is little local recharge of freshwater to the Floridan aquifer. Most of the recharge of freshwater to the aquifer occurs in adjacent Orange and Osceola Counties.

In 1978, draft from Lake Washington for public supply was 10 to 12 Mgal/d. An analysis (Post, Buckley, Schuh and Jernigan, Inc., 1980, p. 5-12) indicated the maximum sustained yield of Lake Washington should be 14 to 15 Mgal/d.

Projected population growth and future water use for the area presently served by Lake Washington (Post, Buckley, Schuh and Jernigan, Inc., 1981) are as follows:

	1980	1985	1990	1995
Population	127,700	157,100	176,500	189,600
Water use (Mgal/d)	15.5	19.1	21.4	23.0

By 1985, water use for southern Brevard County will clearly exceed the maximum yield of Lake Washington. This study is part of an evaluation of alternative sources of water to meet the projected water needs of south Brevard County.

Purpose and Scope

The purpose of this study was to develop, interpret, and present geohydrologic information on the quantity, quality, and water-supply potential of the Floridan aquifer in east-central Florida that will allow water-management interests to properly evaluate this resource as one alternative for future water supplies. Specific objectives were:

1. To describe the occurrence of freshwater in the Floridan aquifer. This included locating the zones of lateral transition of fresh to nonpotable water and determining the approximate depth to nonpotable water.

2. To evaluate the hydraulic characteristics of the Floridan aquifer and the confining materials that overlie and partly control recharge to the aquifer.

3. To design and implement a background (pre-well field) ground-water monitoring system.

4. To simulate by digital computer model the likely hydraulic response (drawdown) of a hypothetical well field(s) pumping at various sustained rates from wells located in various configurations in the Floridan aquifer.

The investigation was made from July 1978 to July 1982 in cooperation with the Board of County Commissioners, Brevard County. This report presents information on water quality, hydraulic characteristics, and drawdown simulations for the Floridan aquifer.

Acknowledgments

The authors thank the landowners of Brevard and Osceola counties, in general, and Deseret Ranches of Florida (managed by Harvey A. Dahl), in particular, for access to their land and allowing data to be collected from their wells. The authors are also grateful for the cooperation received from the Florida Bureau of Geology, St. Johns River Water Management District, and South Florida Water Management District for geophysical logs and access to observation wells.

Other Studies

Several reconnaissance studies have been made in the area, but little has been done to define the hydraulic parameters necessary to quantify the ground-water potential prior to the period of the present study. Lichtler (1972) appraised the water resources of seven counties in east-central Florida that included the report area; Snell and Anderson (1970) discussed the water resources of the St. Johns River basin; Brown and others (1962a, 1962b) discussed and presented an intensive data reconnaissance of Brevard County; and Frazee (1980) presented reconnaissance ground-water information on Osceola County. Potentiometric surface maps of the Floridan aquifer, prepared by the U.S. Geological Survey, are available for annual high and low water conditions for 1965 through 1980.

Concurrent with this study, a broad regional assessment of the Floridan aquifer was being made under the U.S. Geological Survey Regional Aquifer Systems Analysis (RASA) program. As part of the RASA program, Tibbals (1981) presented a computer simulation of the Floridan for a larger area in east-central and northeast Florida which includes the area of this report.

General Description of the Study Area

The study area, located in east-central Florida (fig. 1), consists of most of Osceola and Brevard Counties and parts of Lake, Orange, and Polk Counties. The area modeled measures 54 miles in a north-south direction, and 84 miles in an east-west direction (fig. 1).

Two major streams, the St. Johns and Kissimmee Rivers, have their headwaters in the study area. Their drainage areas are controlled by topographic features that resulted from sea level fluctuations. The St. Johns River lies between features that formed when the level of the sea was about 30 feet higher than at present (fig. 2). On the east, the Atlantic Coastal Ridge, a relict beach ridge, is a divide for drainage flowing to the Indian River (an estuary connected to the Atlantic Ocean) and the St. Johns River.

The valley of the St. Johns River is bounded on the west by the Pamlico Scarp, believed to be the shoreline of the sea at the 30-foot level (White, 1958). Altitudes rise from 30 feet at the base to 50 feet at the top of the scarp, and continue to increase to the west where an elongated swell composed of several beach ridges (Osceola Plain) forms the divide between the St. Johns and Kissimmee Rivers. The width of the swell ranges between 10 and 20 miles and crests at an altitude of about 70 feet. The western side of the swell ends as a scarp that drops into the alluvial plain of the Kissimmee River.

North of Lake Kissimmee, the valley of the Kissimmee river widens and opens into a large group of lakes. The altitude of the valley is about 50 feet. The western edge of the Kissimmee River valley is bounded by the Lake Wales Ridge, one of the most prominent topographic features of Florida. This ridge attains altitudes of nearly 300 feet in the study area and is thought to be a residual highland that was dissected by streams. Coastal erosion straightened its flanks when the sea level was about 100 feet (White, 1970).

The geologic history (White, 1970) of the Florida peninsula has been dominated by repeated inundations of the land and recessions of the sea. In the study area, the resultant land surface features are those of a coastal plain that reflect erosional and depositional events. From previous studies, the geometry of the ground-water system has been defined dividing the system into three layers: a surficial aquifer, a confining layer between the aquifers, and the Floridan aquifer. The surficial aquifer is comprised mainly of sand; it is present throughout the study area. The second layer, which includes the Hawthorn Formation, separates the two aquifers and is comprised chiefly of clays, silts, marls, dense limestone, and fine sediments that do not readily transmit water. This restriction of flow causes artesian conditions in the Floridan aquifer. Locally, thin, discontinuous beds of shell

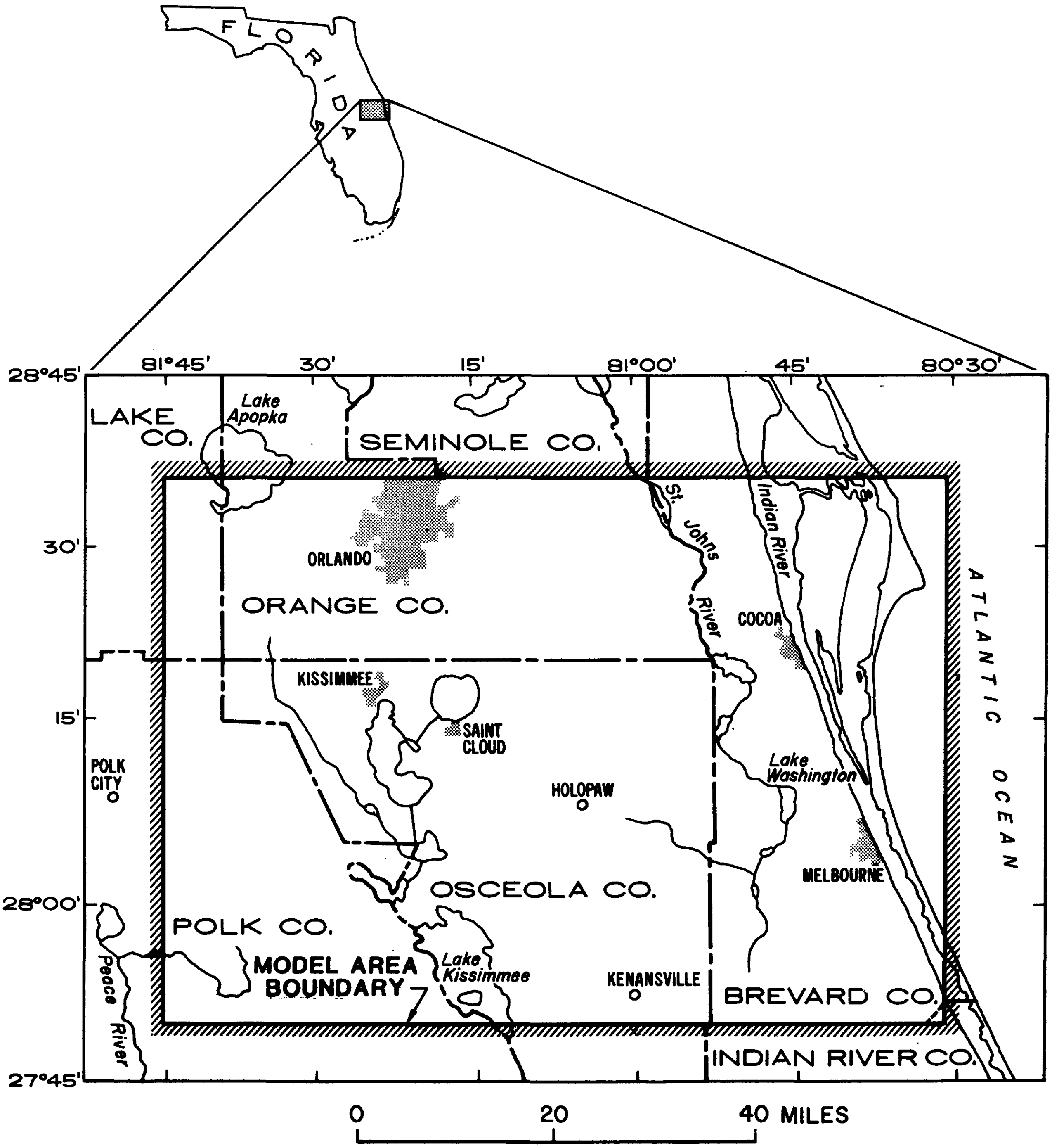


Figure 1.--Location of the study area.

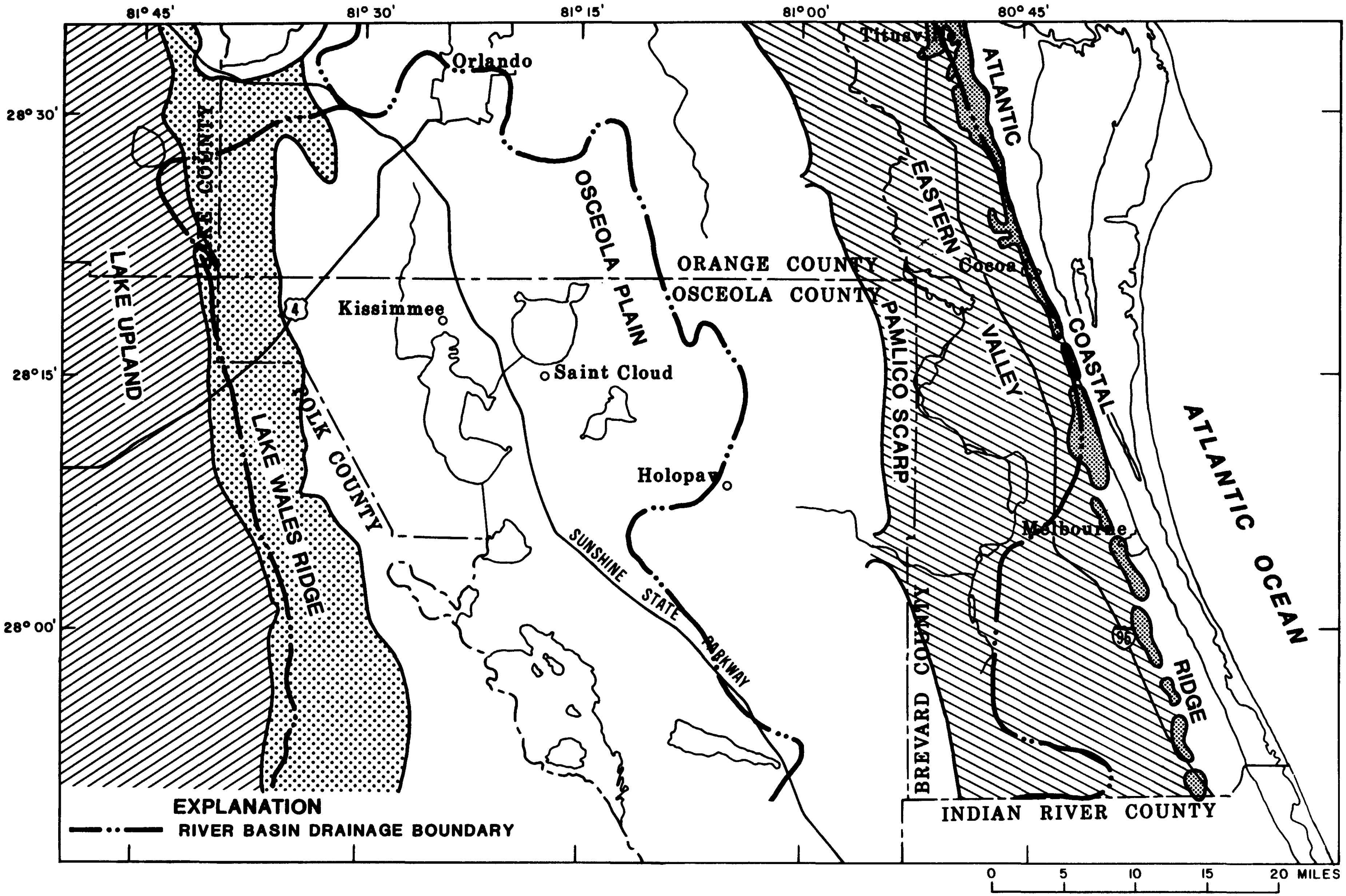


Figure 2.--Physiographic features in the study area (from White, 1970).

or beds of shell material, limestone, or sand and gravel occur above or in the upper part of the Hawthorn Formation, and are confined both above and below by materials which have a lower permeability. These are referred to as secondary artesian aquifers and can yield as much as 1,000 gal/min to wells, but are not areally extensive enough to be considered as a source for major supplies (Lichtler, 1972). The lowermost aquifer, the Floridan, consists of a series of limestone and dolomite formations which have a total thickness of a few thousand feet. However, the thickness containing potable water (less than 250 mg/L chloride) rapidly diminishes seaward into Brevard County.

The climate of the study area is humid subtropical, generally characterized by hot, wet summers and warm, dry winters. However, during the period of this study, drought conditions prevailed during the years 1980 and 1981. Average annual precipitation was 53.52 inches for the four stations shown in table 1, but for 1980 their average was 40.04 inches (National Oceanic and Atmospheric Administration, 1980).

Table 1.--Precipitation data for four selected stations, 1979 and 1980 records

[From National Oceanic and Atmospheric Administration, 1980]

Station name	Precipitation (inches)		
	Mean (1941-70)	1979	1980
Melbourne	50.79	50.79	35.95
Titusville	59.20	---	40.15
Orlando (McCoy)	51.21	50.23	41.21
Lake Alfred	52.87	64.40	42.75

Data Collection

Few data were available in the areas of Osceola County, believed most favorable for potential ground-water development. These areas consist of large ranchlands where the Floridan aquifer is not used because ample water for stock is available from the surficial aquifer.

After existing data were reviewed, an inventory of wells was made to establish a network of data points that define the regional characteristics of the aquifer system (fig. 3). Data from the network gave information on geology, water chemistry, and the hydraulic properties of the aquifer. Where data were not available, wells were drilled to obtain additional information.

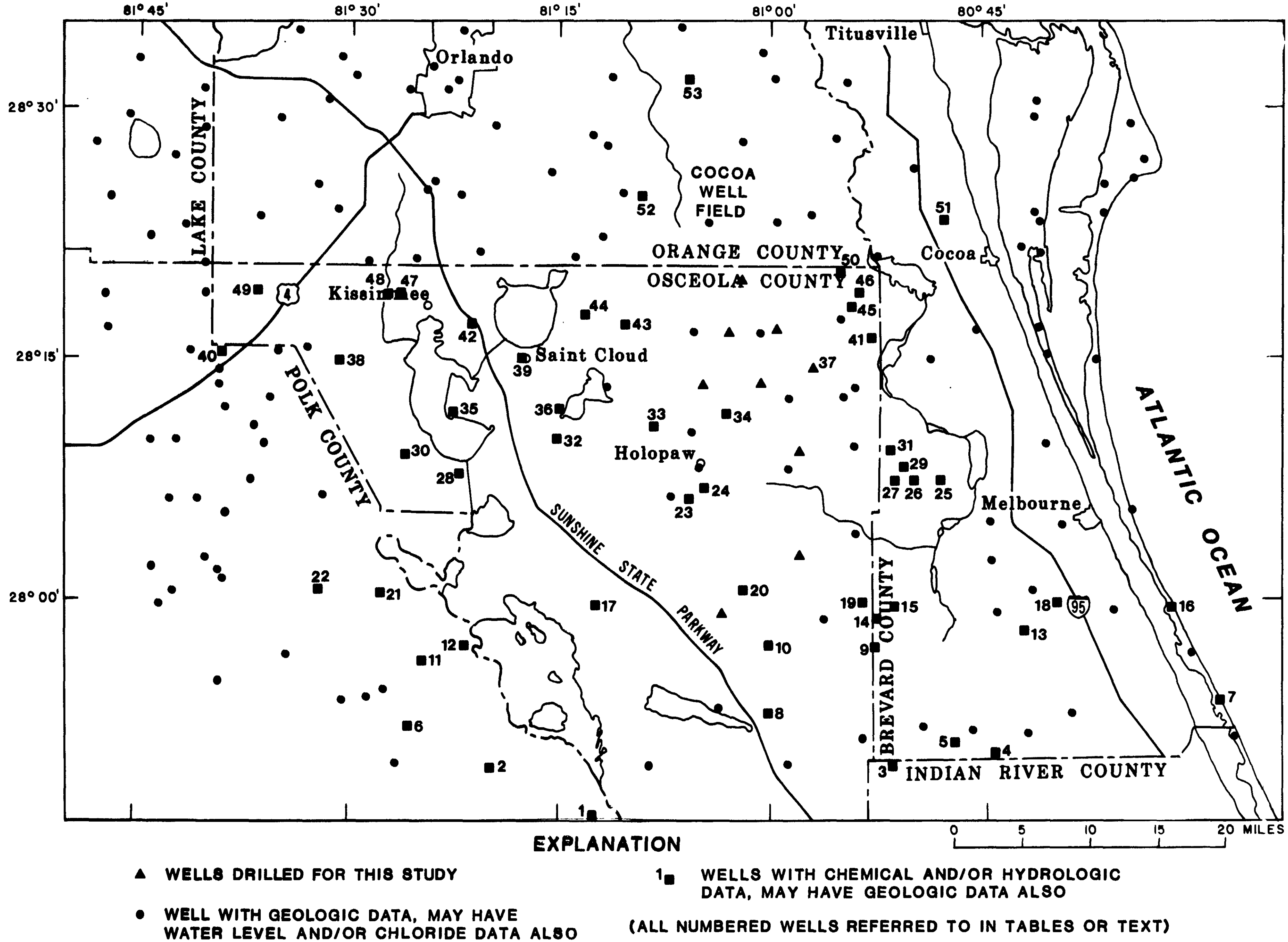


Figure 3.--Location of wells with geologic, hydrologic, and chemical data.

Ground-water levels and chloride measurements were made in May and September of 1979 and 1980 to determine their range of values over the network. All accessible wells were geophysically logged to determine the depth to the top of the Floridan aquifer, the thickness of the confining layer, the location of cavity zones in the limestone, and any vertical variation in water quality within a well that could be attributed to one specific zone of the open borehole.

Two aquifer tests were performed to define properties of the surficial aquifer and the confining materials. The entire network was sampled for chloride data, and 13 wells were sampled to define the concentrations of major ions.

GEOHYDROLOGY

Major Lithologic Units

The study area is underlain in ascending order by limestones of Eocene age, the Hawthorn Formation, and unconsolidated sediments of Miocene to Pleistocene and Holocene age. The spatial distribution and hydraulic properties of these units vary throughout the region. Lithologic information was obtained from 175 geophysical logs collected or on file in the Orlando office of the U.S. Geological Survey, and sample cuttings and drillers' logs of nine test wells (fig. 3).

The formations of Eocene age that comprise the Floridan aquifer, in descending order, consist of the Ocala, Avon Park, Lake City, and Oldsmar Limestones (fig. 4). Little is known about the thickness of the middle two formations because few wells completely penetrate either formation. Both, however, underlie the entire area and consist of white to brown, soft to hard, dense, fossiliferous, and dolomitic limestones. The Oldsmar Limestone is not known to be penetrated by water wells in the study area and is not shown in figure 4.

The Eocene formations contain cavities and solution channels that can yield large quantities of water. Dense and less permeable zones that probably restrict the vertical movement of water in the Floridan aquifer are common. Low permeability zones in the Avon Park and Lake City Limestones comprise a less permeable zone within the Floridan that separates the upper permeable zones of the Floridan from the permeable zones that comprise the lower Floridan aquifer.

Most Floridan aquifer wells in the study area penetrate only the Ocala Limestone which overlies the Avon Park Limestone (fig. 4). The Ocala Limestone consists of white to cream, fossiliferous limestones. The top of the Ocala Limestone is also the top of the Floridan aquifer in the study area and varies in altitude as indicated in figure 5. The Ocala Limestone does not contain the dense layers of dolomite of relatively low permeability that are characteristic of the Avon Park and Lake City Limestones. As a result the Ocala is hydraulically connected to the underlying Avon Park. Wells can produce large quantities of water from cavities and solution channels in the Ocala Limestone.

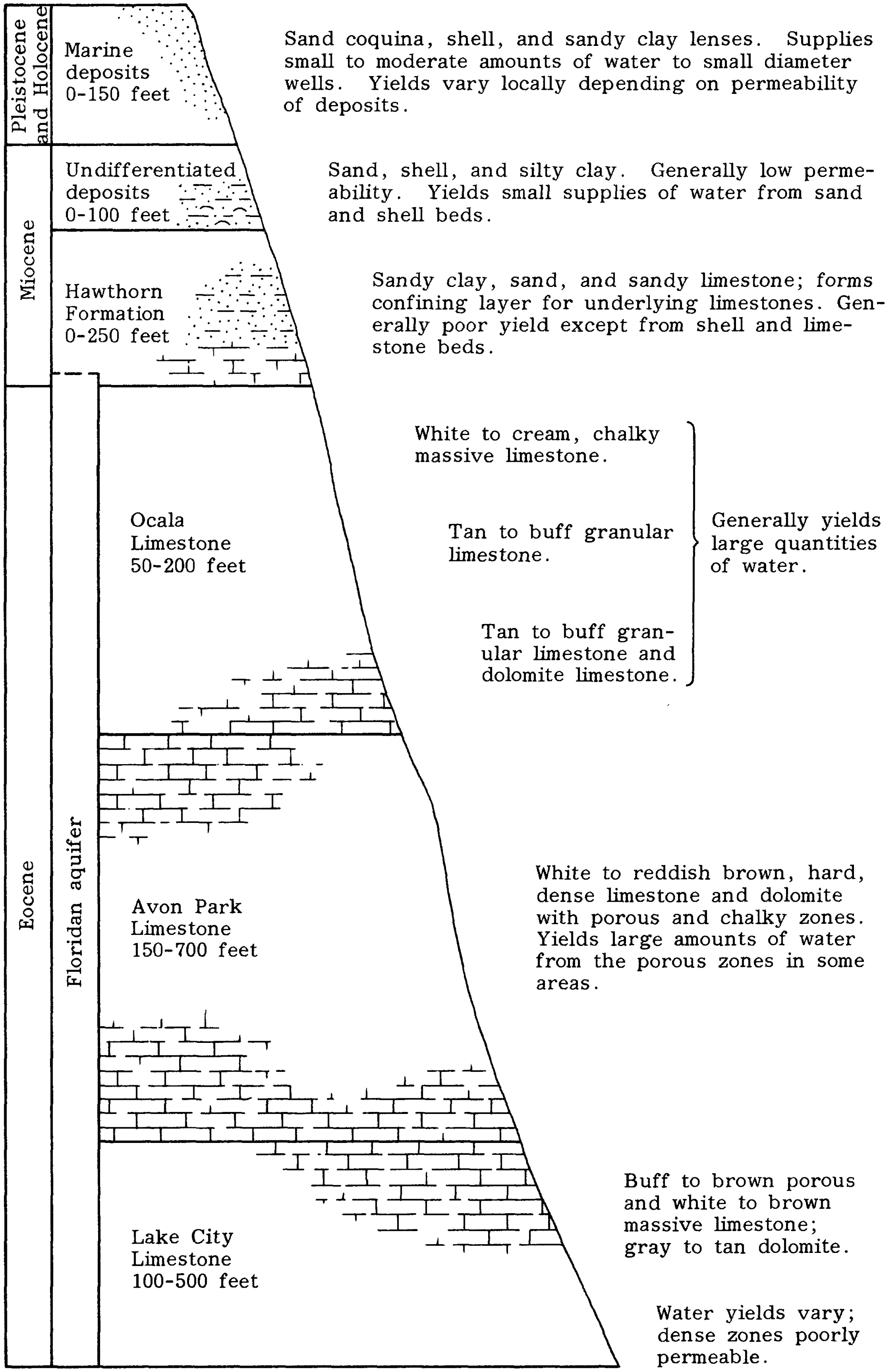
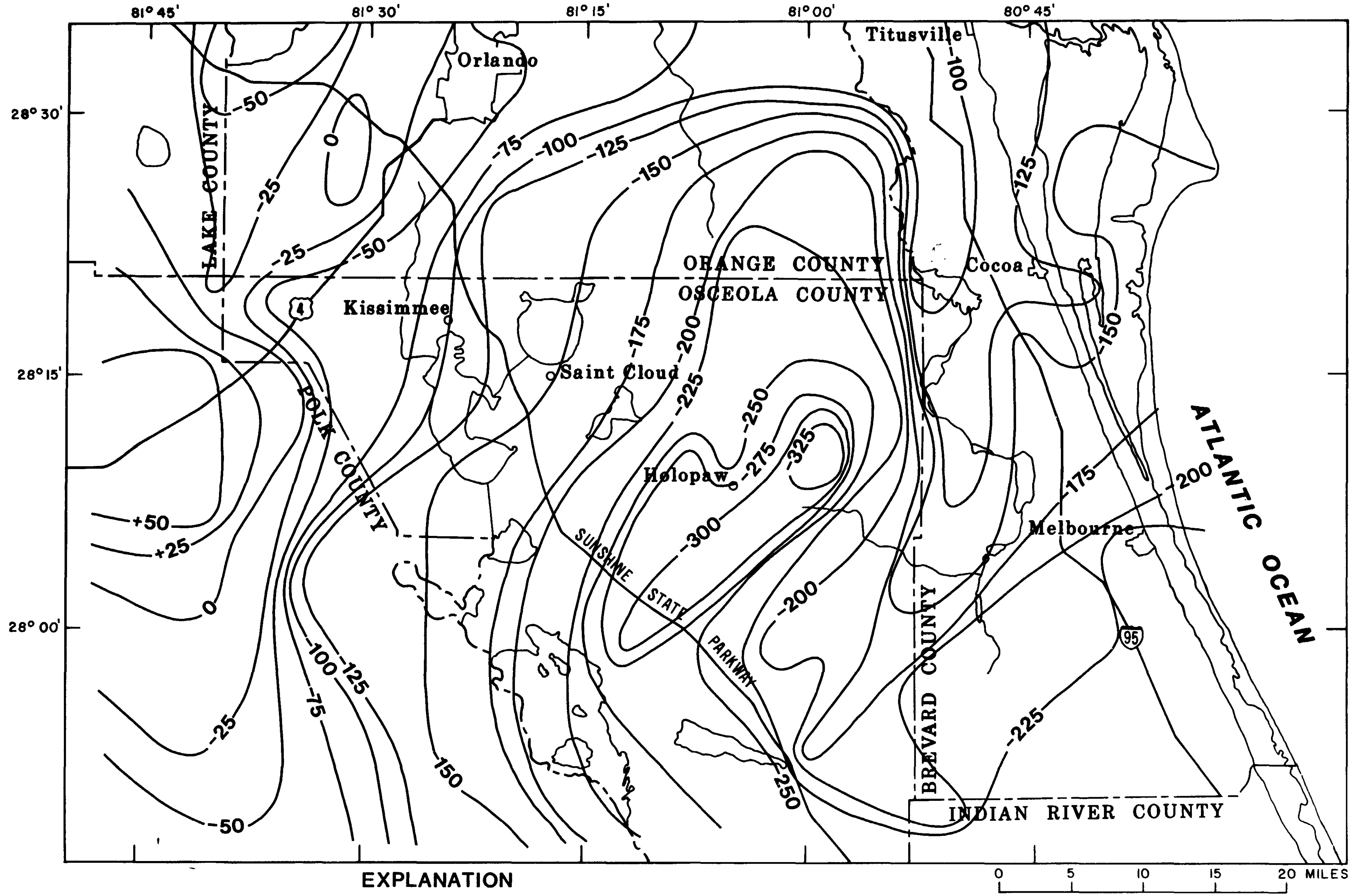


Figure 4.--Geologic column showing formations penetrated by water wells in the study area (from Snell and Anderson, 1970).



EXPLANATION

—— -50 —— STRUCTURE CONTOUR, shows altitude of the top of the Floridan aquifer. Contour interval is 25 feet. Datum is sea level.

Figure 5.--Altitude of the top of the Floridan aquifer.

The Hawthorn Formation of Miocene age unconformably overlies the Eocene in most of the study area. Thickness of the formation varies from less than 25 feet in northwest Osceola County to over 275 feet in northeast Osceola (fig. 6). The Hawthorn consists of clay, silt, sand, and limestone. Because the Hawthorn contains clay beds, its vertical hydraulic conductivity is much lower than the overlying surficial deposits or the underlying Floridan. Therefore, water in the underlying Floridan aquifer and in the beds of higher permeability within the Hawthorn Formation itself is confined, and thus, under artesian pressure.

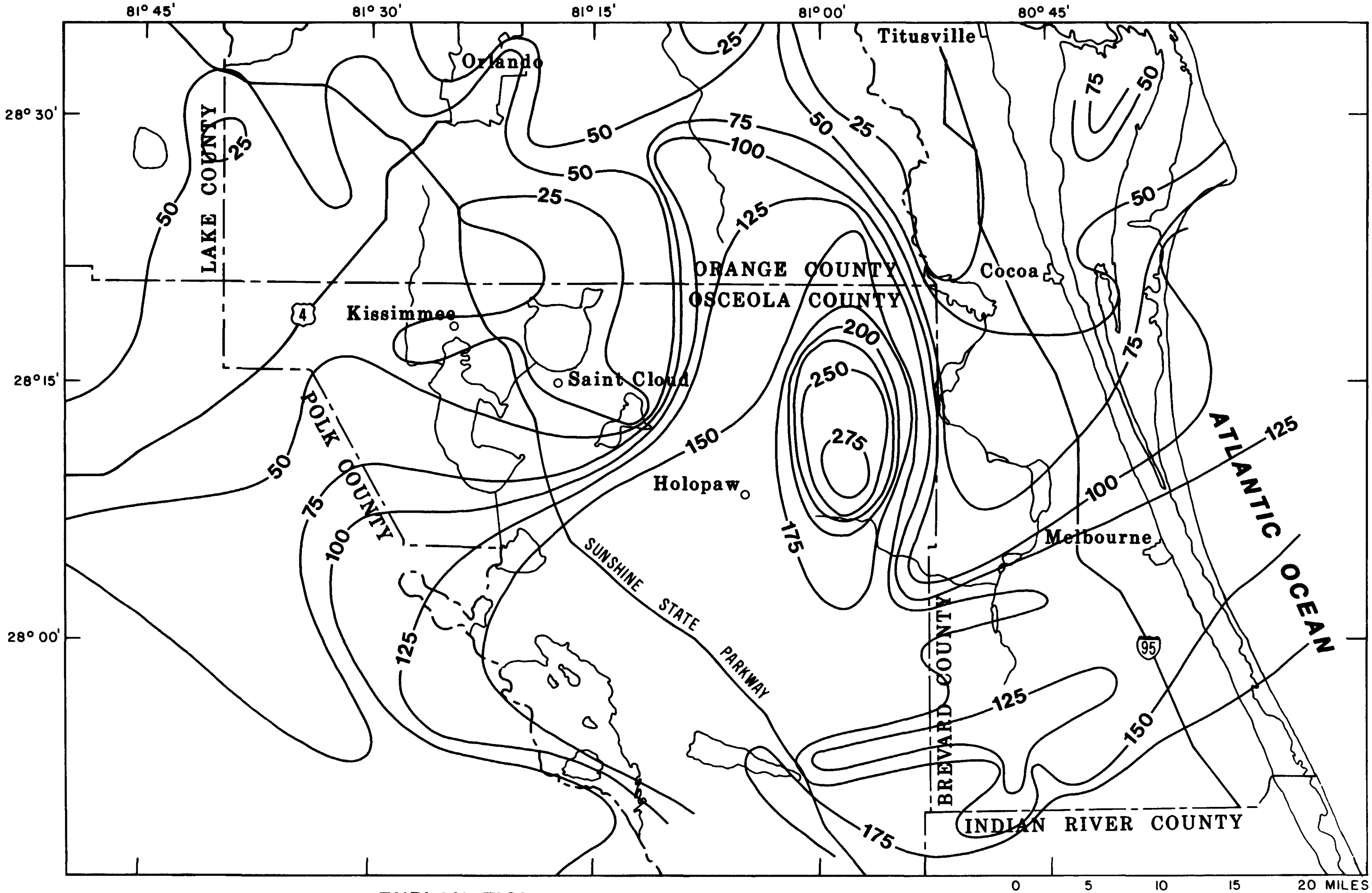
The surficial deposits consist of unconsolidated sand and shells with some silt and clay of Miocene to Pleistocene and Holocene age. The deposits form an aquifer that ranges from less than 20 to over 80 feet in thickness. Water table conditions occur in the upper zones of the surficial aquifer, and some lower zones are confined; it produces adequate domestic and some irrigation water supplies. Lower zones of the surficial deposits that consist primarily of clay can be included with the Hawthorn Formation as forming the confining layer between the surficial aquifer and the Floridan aquifer.

Ground-Water Flow

The driving force for movement of ground water is gravity, and the direction of movement can be determined by the differences in heads within and between aquifers. In a layered system, flow is downward when heads decrease with depth; under these conditions water in the surficial aquifer recharges the underlying layers. Flow is upward when heads increase with depth; under these conditions water discharges from the aquifers to some point such as a stream, spring, or the ocean.

The ground-water flow regime was determined using 114 observation wells in the Floridan aquifer. Water-level data were collected continuously in eight wells and at least semiannually for all others. Five surficial aquifer wells were also measured to determine the depth and fluctuations of the water table; data from these key wells were used in conjunction with topographic maps and lake and stream levels to provide an areawide estimate of the water-table configuration.

Figure 7 is a conceptual east-west cross section of the hydrologic system. The water table in the upper part of the surficial aquifer is generally within 5 feet or less of the land surface in the study area. Precipitation and upward leakage is the source of recharge to the surficial aquifer. Water is naturally discharged by evapotranspiration to the atmosphere; by lateral flow to streams, lakes and the ocean; and by downward leakage to the Floridan aquifer. Horizontal flow in the confining layer can be considered negligible compared to that in the aquifers. The confining layer's main function in the flow system is to control the amount of water passing between the aquifers. Flow through the confining layer is primarily downward to the Floridan aquifer in the west and central part of the study area. Flow is upward along the Kissimmee River and in the eastern part of the area where the Floridan aquifer recharges the surficial aquifer.



EXPLANATION

—125— LINE OF EQUAL THICKNESS, of Hawthorn Formation. Interval is 25 feet.

Figure 6.--Thickness of the Hawthorn Formation.

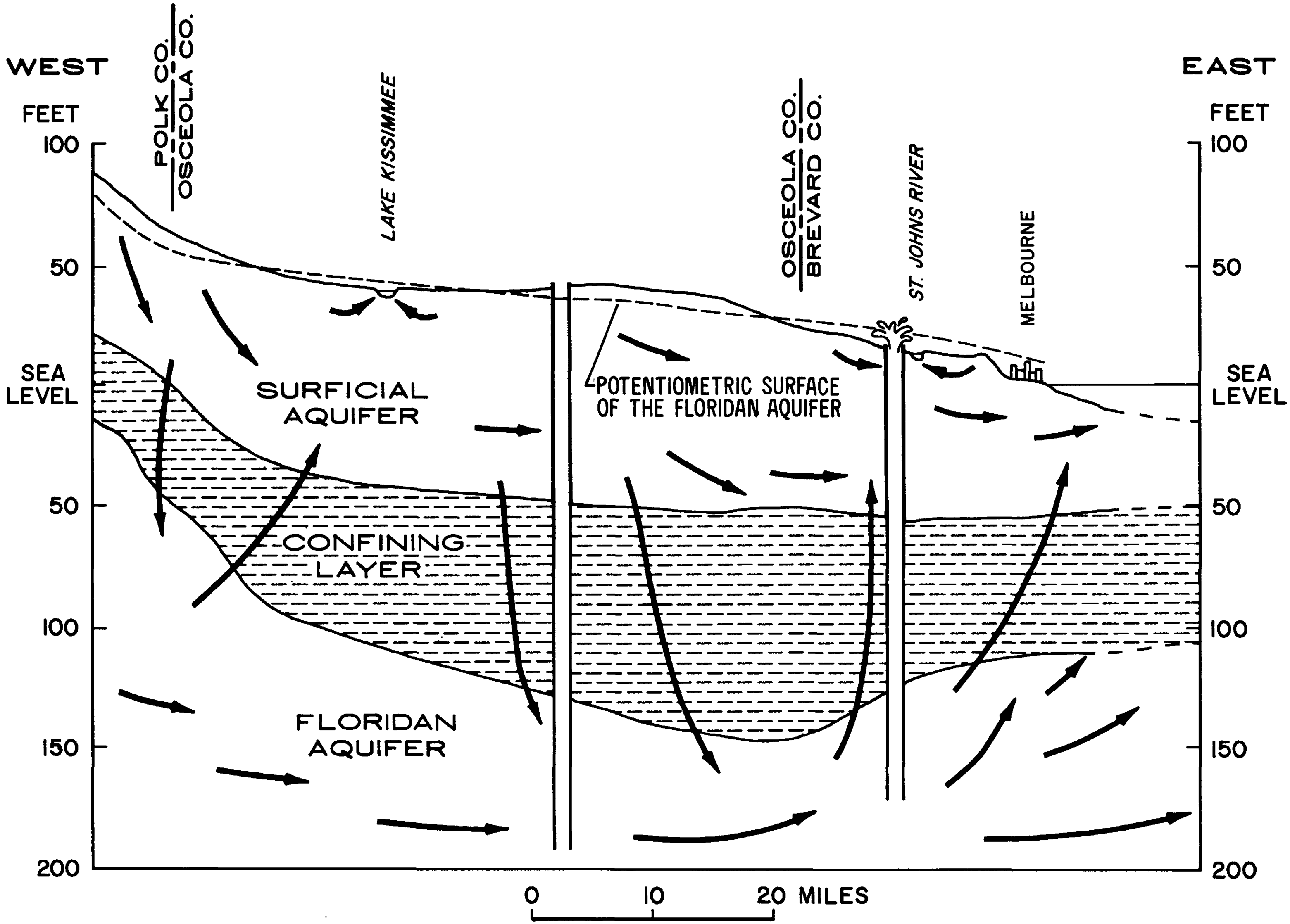


Figure 7.--Generalized east-west geologic section showing aquifers and direction of ground-water movement.

The potentiometric surface of the Floridan aquifer is conceptualized in figure 7 and mapped in figure 8. The potentiometric surface high in Polk County (fig. 8) is the divide between ground-water flowing to the east and west coasts of the Florida peninsula in the Floridan aquifer. Along the Lake Wales ridge (fig. 9), the confining layer between the surficial and Floridan aquifer is thin, or absent, and the Floridan is being vigorously recharged. Within the Kissimmee River valley, land surface altitudes are below the potentiometric surface of the Floridan aquifer and some discharge occurs. The presence of a competent confining layer prevents the Kissimmee River from being the ultimate drain for the Floridan at this point and some water continues to flow past the river towards the ocean. In central Osceola County, along the Osceola Plain (fig. 2), land surface altitudes and the water table are again above the potentiometric surface and there is some recharge to the Floridan aquifer. The presence of the confining layer prevents high rates of recharge into the Floridan, such as occur along the Lake Wales Ridge. East of the base of Pamlico Scarp, the potentiometric surface of the Floridan is above land surface altitude except for small areas along the Atlantic Coastal Ridge. No recharge to the Floridan aquifer occurs in this area where the potentiometric surface is above land surface.

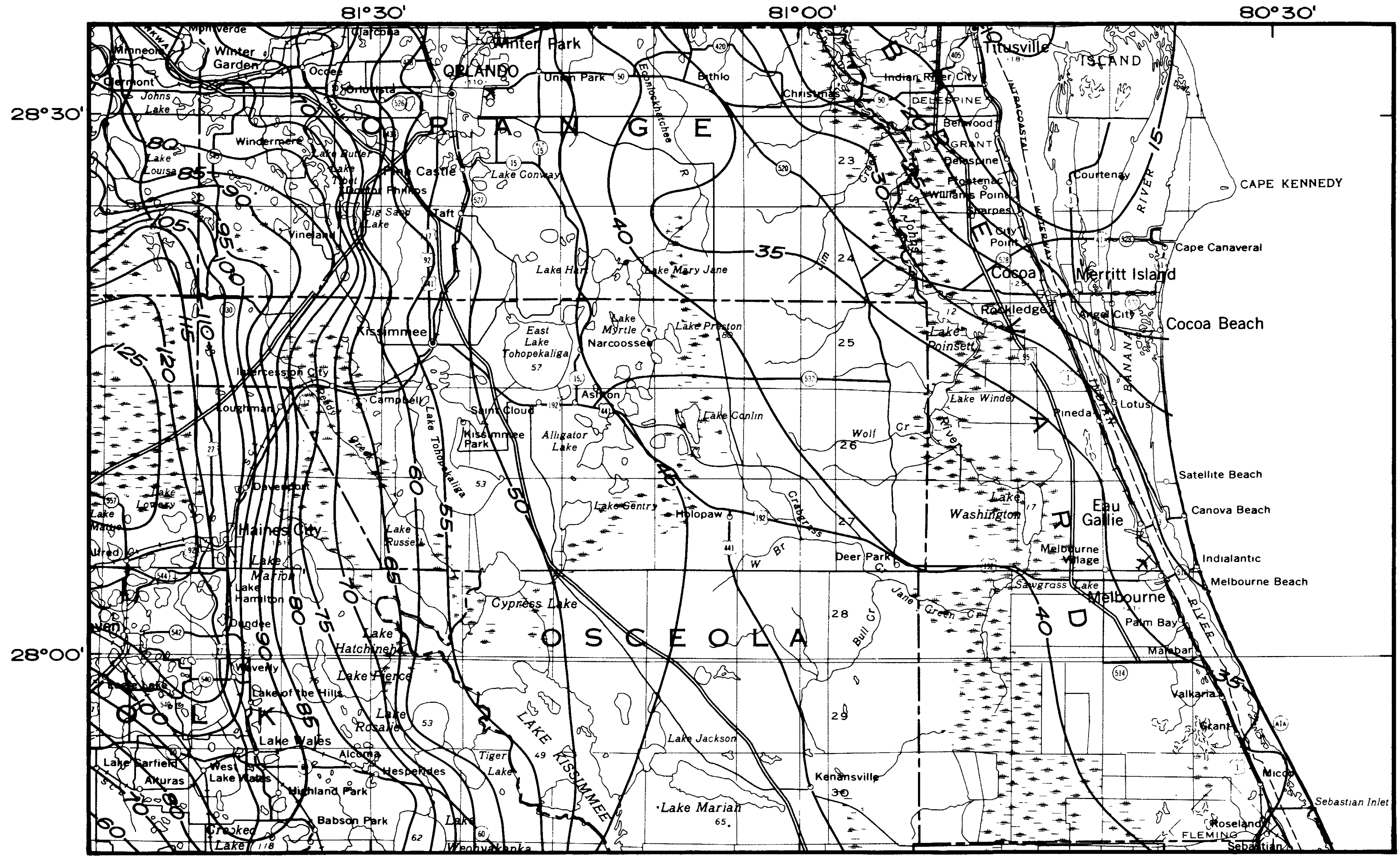
The Floridan tends to separate into upper and lower permeable zones by occurrence of dense layers within the Avon Park and Lake City Limestones. The less permeable zone is not impermeable, thus leakage occurs from the upper Floridan to the lower Floridan in recharge areas and from the lower Floridan to the upper Floridan in discharge areas.

Hydraulic Characteristics of Aquifer Materials

Transmissivity of the Limestone

The Floridan aquifer in Florida is one of the most prolific aquifers in the world. Freshwater flow has opened and enlarged solution channels through the limestone to produce zones of very high yield when tapped by wells. Transmissivity estimates are based on data collected from single well tests. The large area encompassed by the study plus cost factors prohibited extensive aquifer tests from being performed. Availability of wells for testing was a major problem in obtaining a good areal distribution of transmissivity data. Wells equipped with pumps were usually connected to closed water supply or irrigation systems, so that it was not possible to measure flow rates or heads. In eastern Osceola County, there is a large area where no Floridan aquifer wells had been drilled. Test holes drilled by the U.S. Geological Survey (fig. 3) for geologic data could not be pumped because bends in the 4-inch PVC casing prevented pump installation. Most transmissivity data were thus obtained from flowing wells which were generally easily accessible and did not require a pump for testing.

Specific capacity tests for 19 wells were used to obtain one spatial average value for the hydraulic conductivity of the limestone. Eleven tests were made on flowing wells and eight tests were on pumped wells. A method by Brown (1963a, p. 336-338) was used to estimate transmissivity from the specific capacity data. For the analysis, a storage coefficient



EXPLANATION

——80—— **POTENTIOMETRIC CONTOUR--Shows elevation at which water levels would have stood in tightly cased wells. Interval 5 feet. Datum is sea level.**

0 5 10 15 20 MILES

Figure 8.--Potentiometric surface of the Floridan aquifer, September 1980. (From Schiner and Hayes, 1980.)

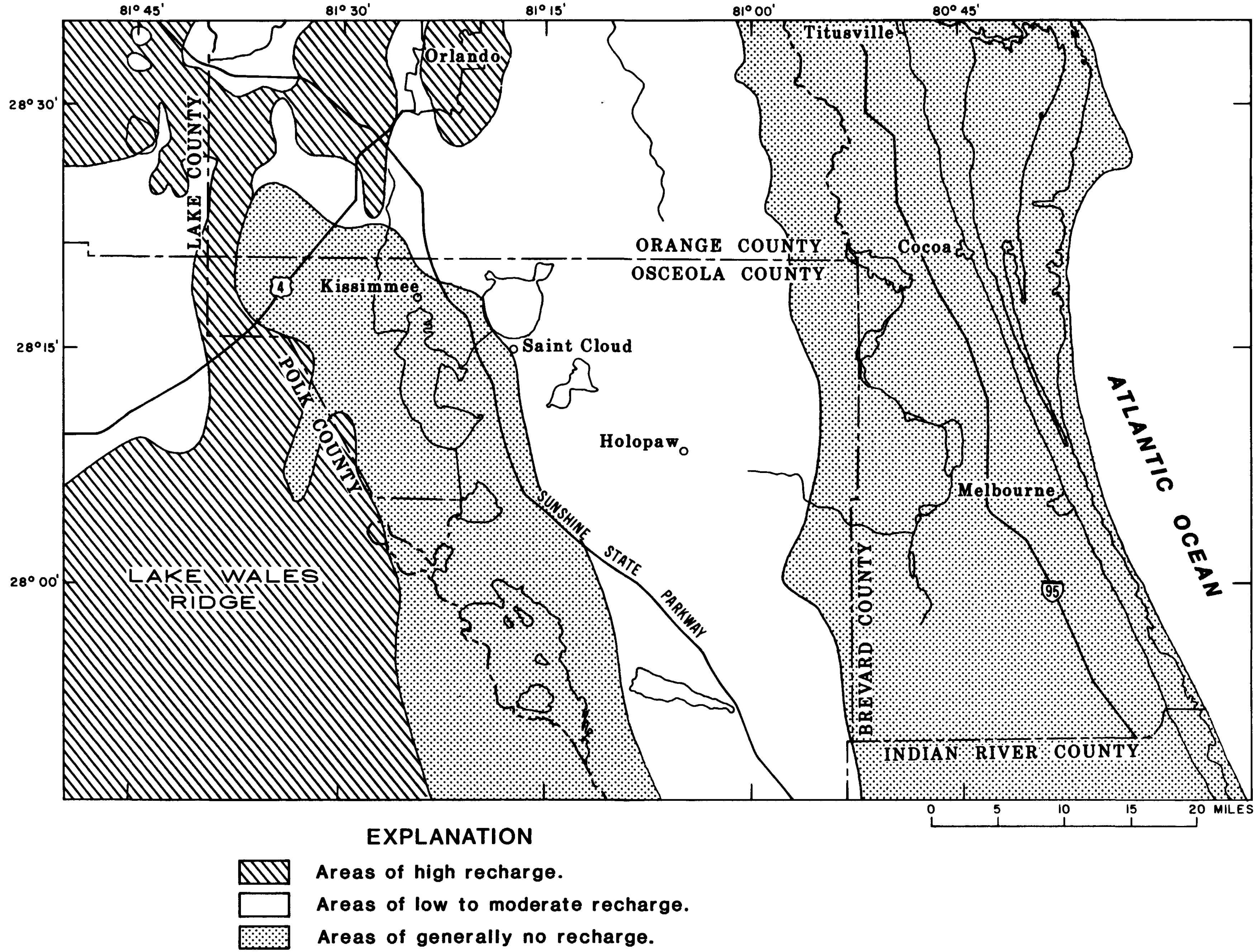


Figure 9.--Areas of recharge based on head differences between the surficial aquifer and Floridan aquifer systems (from Phelps, 1984).

of 2.0 x 10^{-4} and a pumping period of one day was assumed. The transmissivity values were adjusted for well radius. These values (table 2) were then divided by the thickness of limestone penetrated by the well to obtain the hydraulic conductivity for the limestone. The hydraulic conductivities were then averaged for the 19 wells to give a value of 68 ft/d. The average hydraulic conductivity times the thickness of the Floridan aquifer is used to estimate the initial transmissivity for the aquifer.

Areal Distribution of Transmissivity

The areal distribution of transmissivity for the study area could not be mapped because of lack of control points and the wide range of values. However, the potentiometric surface map was used to evaluate qualitative variations in transmissivity. Changes in the spacing of the potentiometric contours can indicate changes in transmissivity values, assuming that the amount of ground-water flow remains relatively constant from point to point along the flow path. Where contour lines in figure 9 are closely spaced (along the eastern Polk County line), transmisssivity values are probably low, and where the spacing is wide (in central and eastern Osceola County), transmissivity values are probably high. However, variations in transmissivity values of particular zones at various depths in the aquifer may occur at any given location or general area. For example, well 34 (fig. 3) near Holopaw had an anomalously large drawdown of 40 feet--unexpected, because nearby wells had less than 10 feet of drawdown for nearly the same pumping rate (250 gal/min) and length of time. The anomaly was explained after a pump was pulled from well 23, 4 miles south of Holopaw, allowing a suite of geophysical logs to be made that included a flow meter log while the well was pumped at 260 gal/min. Flow measurements were taken above and below fracture or solution zones shown on the caliper log to determine contributions from these zones. Flow meter logs indicate that the uppermost 200 feet of limestone contributed only 17 percent of the flow at this site, indicating that the upper part of the Floridan has a low transmissivity in the area around Holopaw. However, the area of low transmissivity is probably not extensive. A test of well 33, 459 feet deep and 6 miles to the west of well 34, indicated a high transmissivity value. Information on well depths indicates that the trend for the lower transmissivity in the upper part of the Floridan aquifer is to the south, as all irrigation wells drilled along U.S. 441 between Holopaw and Kenansville are deeper than 600 feet. Apparently, a sufficient quantity of water could not be obtained from the upper part of the Floridan aquifer in this area.

The point of this discussion is that the head variations along a flow path are the result of the integrated transmissivity of the entire aquifer thickness and that this study will identify a "regional-in-scope" distribution of transmissivity. These transmissivity values may not be entirely relevant to well-field design at specific locations. Site testing, thus, may be necessary to determine geohydrologic conditions at any particular future well-field site.

Properties of the Unconsolidated Materials

Once pumping begins in the Floridan aquifer, one of many factors that influence the spread of the cone of depression that forms around pumping

Table 2.--Transmissivity and hydraulic conductivity estimates derived from specific capacity tests

Map No.	USGS station No.	Transmissivity (ft^2/d)	Hydraulic conductivity (ft/d)	Total depth (feet below land surface)	Top of limestone (feet below surface)	Limestone penetration (feet)	Casing (feet)	Diameter (inches)	Pumping rate (gal/min)	Drawdown (feet)	Specific capacity [(gal/min)/ft]
5	275119080482401	10,000	29	594	250	344	111	12	282	8.9	32
13	275725080412701	5,000	21	458	222	236	120	6	198	14.0	14
14	275738080521001	8,000	18	695	260	435	114	6	120	4.7	26
15	275831080513501	8,000	25	523	200	323	118	6	220	8.9	25
17	275901081121501	6,000	23	628	370	258	258	10	374	20.4	18
25	280658080465101	9,000	93	252	155	97	84	6	338	12.7	27
26	280746080501601	5,000	172	213	184	29	---	6	214	14.5	15
27	280811080514401	8,000	41	432	235	197	---	6	214	8.4	25
30	280905081270101	6,000	23	398	134	264	134	6	300	17.9	17
31	280947080513401	3,000	9	535	195	340	105	4	142	15.0	9
33	281037081075101	19,000	190	457	357	100	282	8	270	4.0	68
34	281116081024101	2,000	11	512	329	183	210	12	305	44.0	7
36	281159081142801	38,000	127	622	322	300	322	--	430	3.6	119
41	281632080515001	7,000	62	253	140	113	---	6	215	9.9	22
43	281714081093001	83,000	233	740	384	356	389	8	276	1.1	251
44	281719081134001	25,000	105	474	237	237	239	8	380	4.8	79
45	281820080540501	3,000	8	603	226	377	108	8	46	5.0	9
46	281919080533301	4,000	37	343	235	108	163	4	146	11.4	13
49	281955081370701	6,000	67	300	211	89	99	6	240	13.5	18

centers is the amount of water that "leaks" out of or through the confining bed. Two aquifer tests were performed in the surficial aquifer with arrays of observation wells designed to evaluate the hydraulic properties of the unconsolidated aquifer and confining materials.

The tests were designed to be analyzed by the Neuman and Witherspoon (1972) method which requires observation wells in the confining units to determine their properties. To allow the optimum amount of data to be collected, the zones pumped for the tests were artesian sand and shell layers within the surficial aquifer. This allowed observation wells to be placed in confining units above and below the zone pumped. This approach assumes that confining materials at these shallower depths have the same properties as the entire confining unit that separates the surficial aquifer and Floridan aquifer.

The first test site was in the central part of Osceola County in the Three Lakes Wildlife Management area (fig. 10). A total of 14 observation wells were installed in, above, and below the zone that was pumped. The pumped well was 6 inches and the observation wells were 2 inches in diameter. The geologic section at the test site is described in figure 11 together with observation well depths and spacing. The pumped zone was composed of about 20 feet of shells and fine sand.

Prior to the test, all wells were developed with air and pumped a minimum of 30 minutes. The pumping rate averaged 94 gal/min for the 14-hour test. Drawdown in the pumped well was 55 feet for a specific capacity of 1.7 (gal/min)/ft. The zone tested had low permeability; thus, the value obtained established a lower limit for the hydraulic conductivity of the water-yielding surficial aquifer materials. The high leakance through the confining beds and low transmissivity rapidly brought the system to steady-state conditions.

The type curve used to evaluate the test is a plot of the Bessel function described by Jacob (1946). The solution applies to an elastic artesian aquifer that receives recharge from an underlying or overlying semipermeable confining bed. The transmissivity of the fine sand and shell unit was calculated to be 400 ft^2/d. As the analysis was for steady-state conditions, a storage coefficient value could not be computed.

Calculations for vertical hydraulic conductivity of the confining layers, using a method described by Neuman and Witherspoon (1972), were affected by the compressibility of the confining layers which caused a momentary water-level rise in the observation wells before a normal drawdown curve was recorded. The normal decline in water levels did occur within the first 10 minutes of the test, and the values obtained from the analysis are probably within an acceptable range. The Neuman and Witherspoon method of analysis allows for the computation of hydraulic diffusivity which is the vertical hydraulic conductivity divided by the specific storage of the layer. Using a specific storage value of 0.0001 from Neuman and Witherspoon (1972, p. 1297), a vertical hydraulic conductivity of 0.005 ft/d was calculated for the overlying confining bed. Similarly, a value of 0.09 ft/d was obtained for the underlying confining bed.

The second test site is in north-central Osceola County, northeast of Holopaw on the Deseret Ranch (fig. 10). Ten observation wells were used

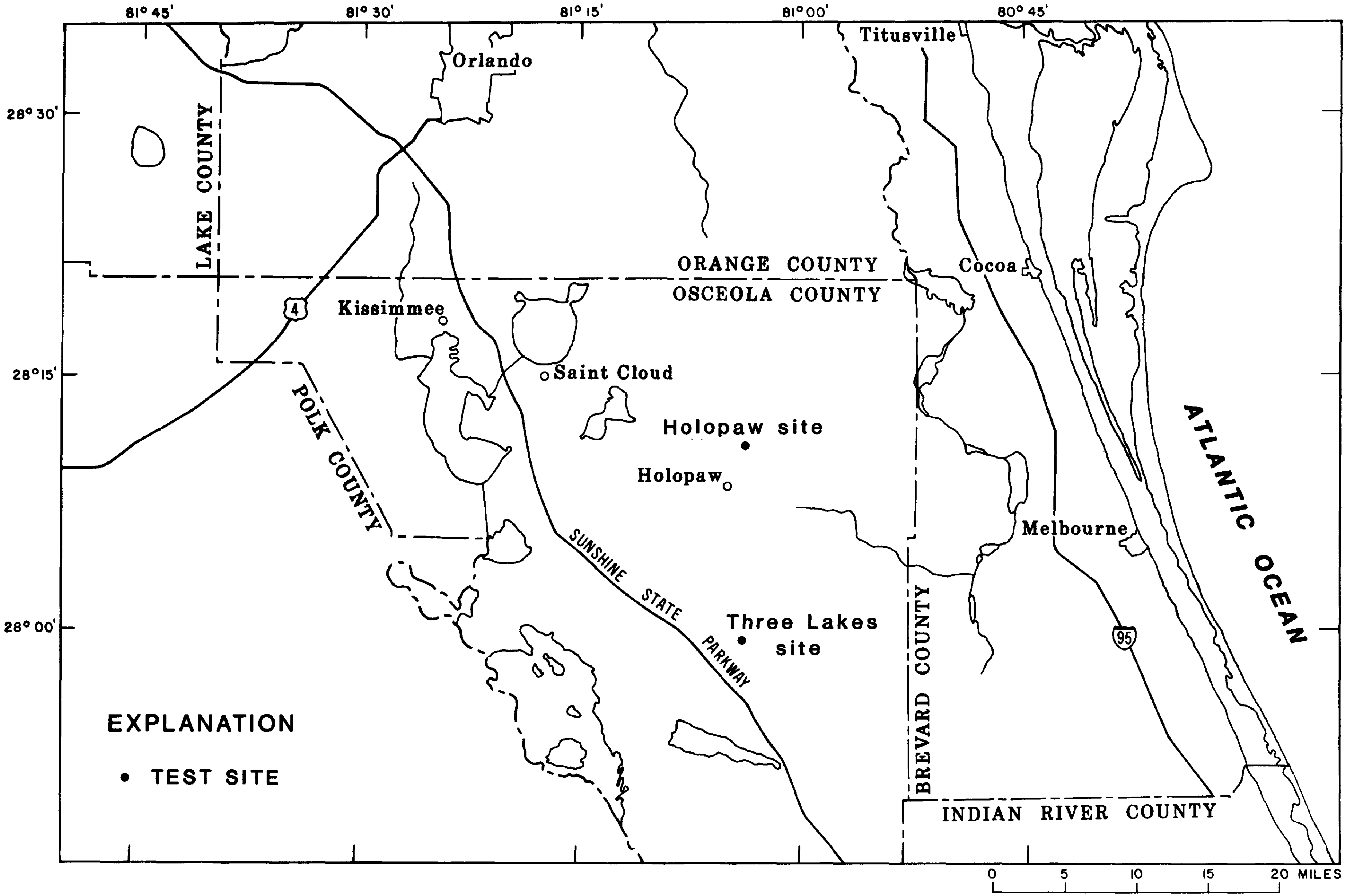


Figure 10.--Location of surficial aquifer test sites.

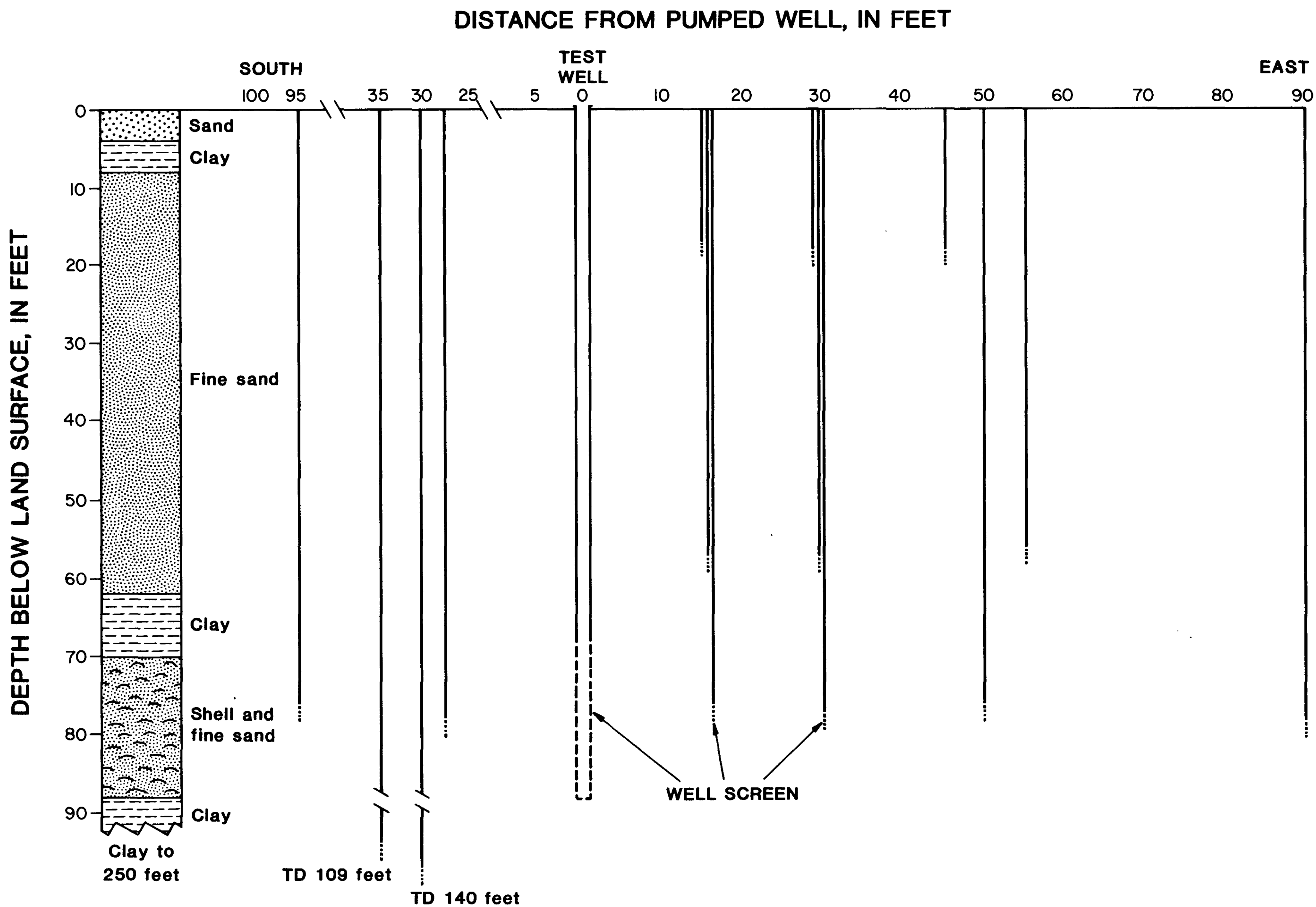


Figure 11.--Geologic column, depth, and spacing of observation wells for aquifer test at Three Lakes Wildlife Management Area.

for this test. Their layout plus the geologic section for the test site are shown in figure 12. The production well was 6 inches in diameter and the observation wells were 2 inches. The pumped zone consisted of a 20-foot thick section of clean shells at the top that grades to gravel-sized limestone fragments in the bottom 7 feet.

The Jacob (1946) method also was used to analyze data from the Holopaw site. The transmissivity for the shell and gravel mixture was 2,000 ft^2/d and the storage coefficient value was 0.0004. As in the first test, observation wells completed in the confining layers showed a small rise in water level before drawdown began. The value for the vertical hydraulic conductivity of the upper confining layer is calculated as 0.05 ft/d by the Neuman and Witherspoon method using a specific storage of 0.0001. The underlying confining layer had a vertical hydraulic conductivity of 1.2 ft/d. The results of the two tests gave values of hydraulic conductivity that ranged from 20 ft/d to 100 ft/d for the aquifer zones tested and 0.005 ft/d to 1.2 ft/d for the confining materials.

Water Quality

Of the many constituents dissolved in ground water in the study area, chloride concentration is the most significant for public water supplies. Determinations of chloride concentrations and measurements of hydraulic head were made for each well in the data network during the first 2 years of the study. Samples from 13 wells were analyzed for major ions and information on 16 wells was available from a concurrent study (Reece and others, 1982). Information on the 29 wells (table 3) showed that chloride concentration and dissolved solids were the only constituents to exceed United States Public Health Service primary standards for drinking water (U.S. Environmental Protection Agency, 1977, p. 17146).

Water samples were taken at the discharge point of the well, thus, the sample was a mixture of waters from all producing zones of a well. Most wells were constructed with the casing set in the first firm clay encountered within the Hawthorn Formation, so permeable layers of the Hawthorn below the casing could potentially contribute water. However, fluid velocity logs indicate little contribution from the Hawthorn Formation. The water quality of wells that tap the Floridan aquifer may depend on the thickness of limestone penetrated, as producing zones may contain water of different quality.

Distribution of Saline Water in the Limestone

A map of chloride concentrations (fig. 13) shows that high chlorides occur along the St. Johns River and further east. Concentrations greater than 250 mg/L can be defined areally in the eastern part of the area, but westward, only individual concentrations can be shown because of their wide range. Near the boundary between recharge and discharge areas, wells that penetrate only a few feet of limestone may yield water with relatively low chloride concentrations. In the discharge areas, the greater heads in the limestone prevent the chloride concentrations from being diluted, as fresher water cannot flow downward into the Floridan aquifer.

Table 3.--Chemical analyses of water

Station No.	Date of sample	Map No.	pH (units)	Specific conductance (umhos)	Carbon-14, dissolved, apparent age (years BP)	Sodium, dissolved (mg/L as NA)	Calcium, dissolved (mg/L as CA)	Potassium, dissolved (mg/L as K)	Magnesium, dissolved (mg/L as MG)	Chloride dissolved (mg/L as CL)	Sulphate dissolved (mg/L as SO_4)
274553081115601	79/09/06	1	7.5	642	---	32	74	0.5	8.3	32	< 5.0
274746081202201	79/05/22	2	8.1	185	---	3.1	19	.8	8.5	11	7.4
274857080493401	80/07/31	3	7.3	1,560	18,000	160	85	4.7	42	330	180
274925080361701	80/07/29	4	7.4	2,970	21,000	360	130	11	69	790	220
275137081252501	79/05/22	6	8.3	130	---	< 3.1	16	.5	5.8	5.9	6.0
275208080271701	80/07/29	7	7.1	980	29,000	84	50	5.0	35	180	84
275233080595101	79/12/21	8	---	740	---	65	65	2.0	14	110	35
275508080510701	79/11/27	9	---	1,550	---	89	59	3.1	33	180	86
275622081252301	79/09/05	11	8.1	180	---	3.3	13	1.0	6.5	6.4	< 5.0
275634081211801	79/05/23	12	8.1	160	---	< 3.1	18	1.0	7.1	8.1	< 5.0
275738080521001	79/11/27	14	---	1,020	---	110	63	3.3	27	200	84
275858080311801	80/07/28	16	7.5	3,020	<2,000	430	76	14	72	790	130
275948080393501	80/07/29	18	7.3	2,680	21,000	290	120	7.9	68	700	150
275957080523401	80/07/31	19	7.4	975	22,000	85	67	2.6	24	180	53
280153081274101	79/09/05	21	7.9	252	---	< 3.0	26	.9	6.5	8.6	23
280229081325201	79/05/23	22	7.9	180	---	< 3.1	25	.9	7.9	5.1	6.0
280539081060201	79/12/06	23	---	1,110	---	130	48	5.2	20	230	51
280632081050101	79/09/13	24	7.6	695	---	41	33	1.9	18	65	12
280820081213901	79/09/06	28	7.7	255	---	3.3	34	.7	4.9	6.8	17
281006081162601	79/09/12	32	7.4	400	---	13	51	1.2	12	9.7	10
281146081211701	79/03/27	35	7.6	295	---	5.6	34	1.2	6.1	7.3	3.2
281354080563301	80/01/02	37	---	1,300	---	160	66	5.7	30	270	58
281356081290901	78/12/08	38	7.6	285	---	3.4	46	.8	7.3	5.4	< 5.0
281456081161101	80/03/12	39	7.2	375	---	11	53	1.1	7.9	12	40
281511081393101	79/09/05	40	7.5	324	---	< 3.0	56	.5	2.6	6.4	6.2
281653081221101	79/09/13	42	7.7	190	---	< 3.0	28	.8	5.7	11	12
281937081245901	79/03/20	47	7.4	245	---	4.7	31	.9	5.4	4.2	17
281937081250101	79/03/20	48	7.5	225	---	4.0	29	.7	5.0	< 4.0	6.5
282052080553101	79/11/16	50	---	2,220	---	270	85	8.5	52	560	100

samples from selected wells

Fluoride, dissolved (mg/L as F)	Bicarbonate fet-flo (mg/L as HCO_3	Alkalinity field (mg/L as $COCO_3$	Nitrogen, nitrite dissolved (mg/L as N)	Nitrogen, nitrate dissolved (mg/L as N)	Nitrogen, ammonia dissolved (mg/L as N)	Nitrogen, ammonia + organic dissolved (mg/L as N)	Phosphorus, total (mg/L as P)	Solids, residue at 180°C dissolved (mg/L)	Solids, residue at 105°C dissolved (mg/L)	Strontium dissolved (ug/L as SR)	Iron, dissolved (ug/L as FE)
---	---	344	---	---	---	---	---	---	370	836	---
---	---	114	---	---	---	---	---	---	130	4,601	50
0.5	150	120	0.000	0.00	0.310	0.25	---	977	---	14,000	30
.5	170	120	.000	.00	.460	.56	---	2,000	---	18,000	60
---	---	88	---	---	---	---	---	---	96	1,537	150
.7	200	140	.000	.03	.340	.45	---	665	---	6,900	10
.7	---	170	---	---	---	---	---	---	411	2,500	---
.9	---	130	---	---	---	---	---	597	---	7,800	---
---	---	92	---	---	---	---	---	---	95	2,211	---
---	---	96	---	---	---	---	---	---	122	1,195	120
.5	---	120	---	---	---	---	---	601	---	11,000	---
.7	170	140	.000	.01	.480	.58	---	1,830	---	13,000	30
.5	---	120	.000	.01	.530	.49	---	1,810	---	15,000	60
.8	180	130	.000	.00	.420	.17	---	600	---	4,400	20
---	---	92	---	---	---	---	---	---	148	342	---
---	123	100	---	---	---	---	---	---	138	< 216	200
.5	---	110	---	---	---	---	---	581	---	9,300	---
---	227	186	---	---	---	---	---	---	---	< 187	---
---	---	129	---	---	---	---	---	---	169	273	---
---	---	176	---	---	---	---	---	---	275	668	---
---	130	106	<.010	.00	.210	<.20	.040	---	138	331	---
1.1	---	160	---	---	---	---	---	720	---	3,500	---
---	---	174	---	---	---	---	---	---	178	272	---
.2	---	140	---	---	---	---	---	232	---	1,300	---
---	190	156	---	---	---	---	---	---	179	< 187	---
---	---	178	---	---	---	---	---	---	127	420	---
---	---	140	<.010	.00	.100	<.20	.060	---	158	250	---
---	---	140	<.010	.00	.100	<.20	.060	125	---	204	---
1.1	---	120	---	---	---	---	---	1,260	---	6,000	---

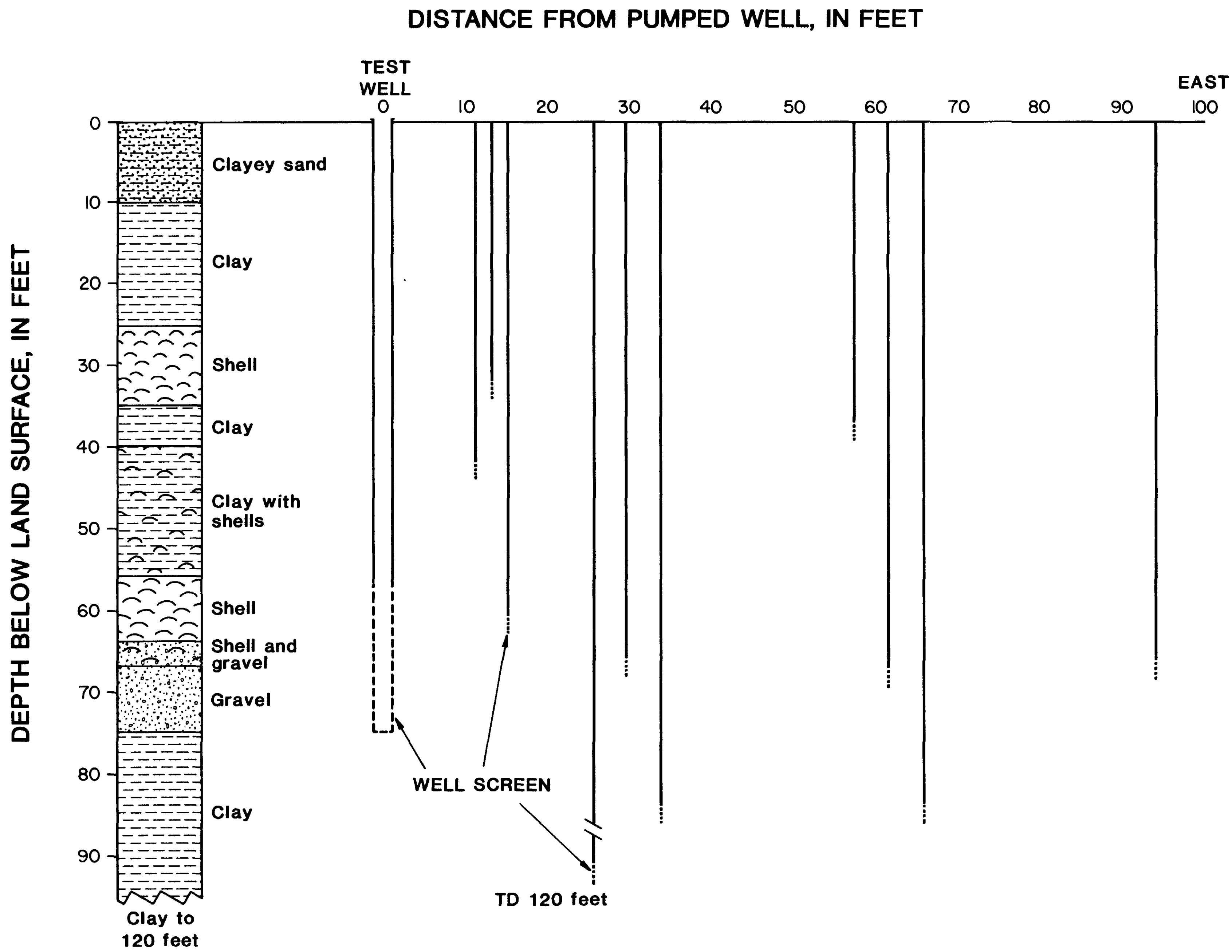
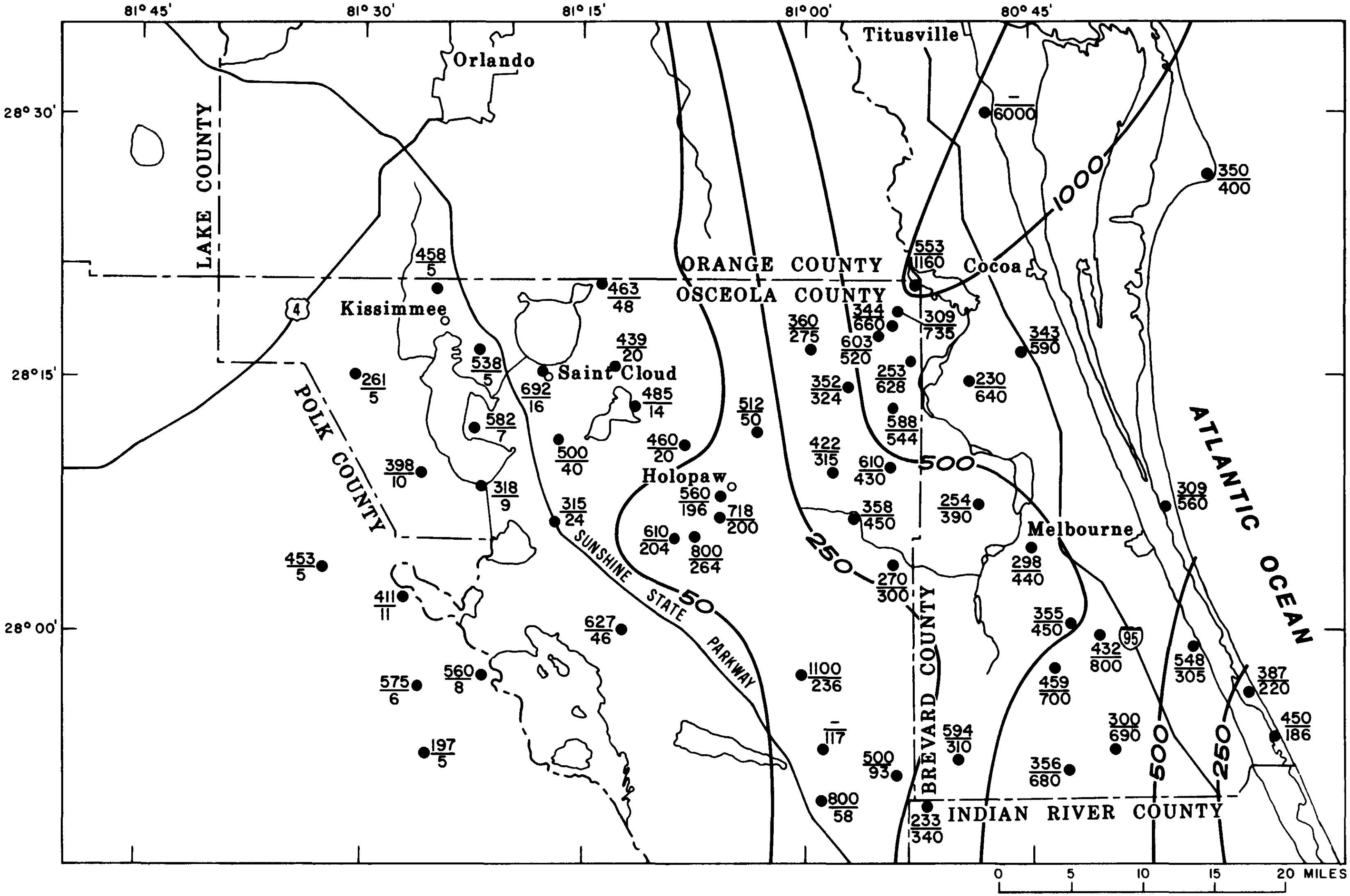


Figure 12.--Geologic column, depth, and spacing of observation wells for aquifer test north of Holopaw.



EXPLANATION

—50— LINE OF EQUAL CHLORIDE CONCENTRATION, in milligrams per liter. Contour interval varies.

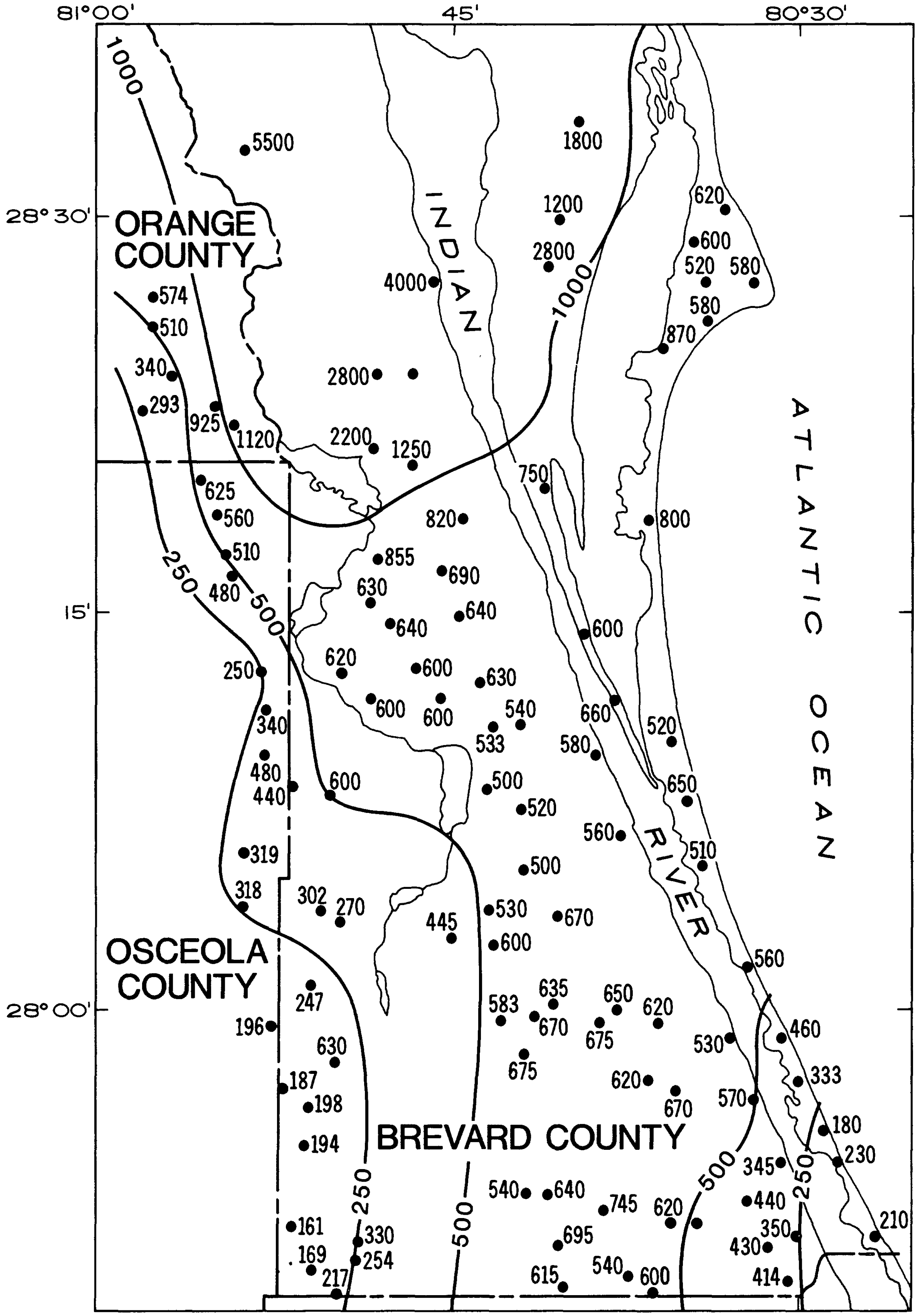
● $\frac{197}{5}$ WELL LOCATION, upper number is depth of well below land surface, in feet. Lower number is chloride concentration in milligrams per liter.

Figure 13.--Chloride concentrations, in milligrams per liter, for the study area in Floridan aquifer system, September 1979.

A distribution of chloride concentration in Brevard County was mapped by J. B. Foster in 1958 (Brown and others, 1962a, fig. 14). Results of the sampling for this study (fig. 13) shows that the distribution in Brevard County has not appreciably changed in 20 years. The only parts of Brevard County included in the study area that contain potable water in the Floridan aquifer are the southeast and southwest corners. However, the chloride values are close to 250 mg/L under unstressed conditions and the possibility of developing large amounts of potable water seems remote, as pumping would probably draw water from the adjacent areas of higher chloride concentrations.

Published information on Floridan aquifer chloride concentrations in Osceola County is sparse. The latest information is a reconnaissance map based on 32 control points for the entire county (Frazee, 1980). Figure 13 shows an area in central Osceola County where chloride concentrations exceed 200 mg/L. All the wells sampled there were drilled since the mapping by Frazee and all have depths greater than 600 feet (fig. 15). This area coincides with the area of low transmissivity in the upper part of the aquifer that was discussed previously. The 800-foot deep well 23 south of Holopaw had a chloride concentration greater than 200 mg/L whereas the concentration of the 512-foot well 34 north of Holopaw was 50 mg/L. Most of the water from the 800-foot well was from below the 600-foot depth, so water with the high chloride concentration occurs below that depth. It is evident that all the irrigation wells along U.S. 441 between Holopaw and Kenansville were drilled into this zone of higher transmissivity and chloride concentration. The extent of higher chloride concentrations in this lower zone seems to be limited to the immediate area of these wells and possibly further east (few wells are drilled deeper than 600 feet east of U.S. 441 in Osceola County from which to determine the lateral extent of the area). Wells deeper than 600 feet that are west and north of this area (fig. 15) have chloride concentrations less than 100 mg/L. Combining the factors of low transmissivity in the upper 200 feet of the limestone aquifer with the higher chloride concentrations below 600 feet indicates that any well fields in Osceola County should be located west of Holopaw.

The data are insufficient to define vertically the regional interface between fresh and nonpotable water within the study area. The only definitive information available is from the Cocoa well field in Orange County. Thirteen wells were constructed between 1956 and 1961, and many wells experienced problems of high chloride concentrations soon after they were placed in operation. Concentrations in most wells were less than 100 mg/L initially, but rose to more than 300 mg/L in some wells (Tibbals and Frazee, 1976). Beginning in 1962, six wells were drilled 4 miles to the west of the original well field and in 1965, a salinity monitor well was constructed to monitor four zones in the Floridan aquifer--approximately 1,000, 1,050, 1,200, and 1,400 feet below land surface. At a depth of about 1,400 feet, the chloride concentration was over 1,000 mg/L, but at a depth of 1,200 feet, the concentration was less than 100 mg/L. As of 1981, the new well field had not experienced the chloride increases that occurred in the old well field. However, water from the two easternmost wells in the new well field has experienced some rise in chloride concentration (Tibbals and Frazee, 1976, p. 26).



Chemical quality by J.B.Foster in 1958.

EXPLANATION

— 250 — LINE OF EQUAL CHLORIDE CONCENTRATION, in milligrams per liter. Interval 250 and 500 milligrams per liter.

217 ● WELL LOCATION, number is chloride concentration.

Figure 14.--Chloride concentrations, in milligrams per liter, for Brevard County in the Floridan aquifer, 1954-58. (From Brown, 1962a.)

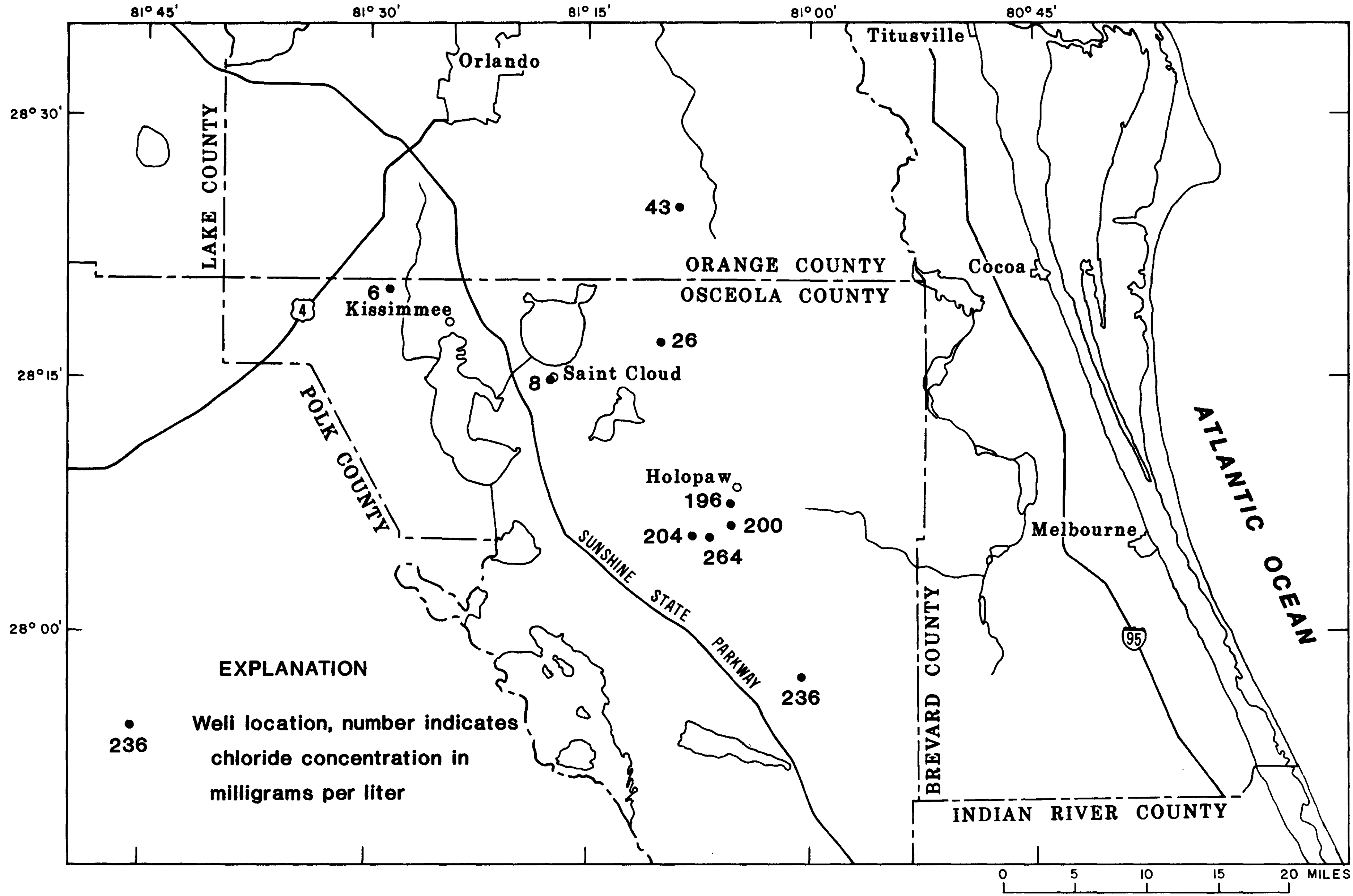


Figure 15.--Chloride concentrations of deep wells within, north, and west of the high chloride area near Holopaw.

Records of water levels over 16 years show that the deep zone is not severely affected by pumping from the new well field, probably owing to a low vertical hydraulic conductivity in the area of the new well field, and that the fluctuations in water levels are controlled mainly by regional variations in the potentiometric surface (Tibbals and Frazee, 1976). Increased pumping in the new well field would lower the head in the pumping zone and would increase the vertical hydraulic gradient between the two zones, thereby increasing the potential danger of drawing saline water from depths. Perhaps more significantly, lowered heads in the new well field area would also increase the lateral east-to-west hydraulic gradient between the old and new well fields. Tibbals and Frazee (1976, p. 46) speculated that the reason the easternmost wells in the new well field were becoming increasingly salty was because of the westward movement of salty water from the old well field area.

Evolution of Water Types

Analyses of data in which major ions are plotted on a Piper diagram (fig. 16) indicate that water from most wells can be classified into one of two groups--one group for samples from wells located in recharge areas and one from wells located in discharge areas. The few scattered points in the Piper diagram that lie between the two groups relate to wells located between the recharge and discharge areas and indicate a progression from one type of water to the other.

Freeze and Cherry (1979, p. 242) discussed the changes recognized by Chebotarev that occur as water in an aquifer moves from the point of recharge to the point of discharge. As the water travels downgradient, certain constituents are dissolved in the process and the water can be classified by the dominant anions present in the water. The following changes describe the evolution in the direction of flow:

$$HCO_3^- \rightarrow HCO_3^- + SO_4^{-2} \rightarrow SO_4^{-2} + HCO_3^- \rightarrow SO_4^{-2} + Cl^- \rightarrow Cl^- + SO_4^{-2} \rightarrow Cl^-$$

The test for evolution in the waters of the study wells comes from numbering the wells from left to right on the anion triangle ($HCO_3^- \rightarrow Cl^-$) of the Piper diagram, then plotting these numbers at the well locations on the map of the potentiometric surface (fig. 17). With the direction of flow from west to east, the lower numbers should appear to the west and the higher numbers to the east. Care must be taken, however, in assuring that the interval of the aquifer sampled is the same for all wells because the Chebotarev sequence can be described in terms of three main zones which correlate with depth (Domenico, 1972):

> "1. The upper zone--characterized by active ground water flushing through relatively well-leached rocks. Water in this zone has HCO_3^- as the dominant anion and is low in total dissolved solids.

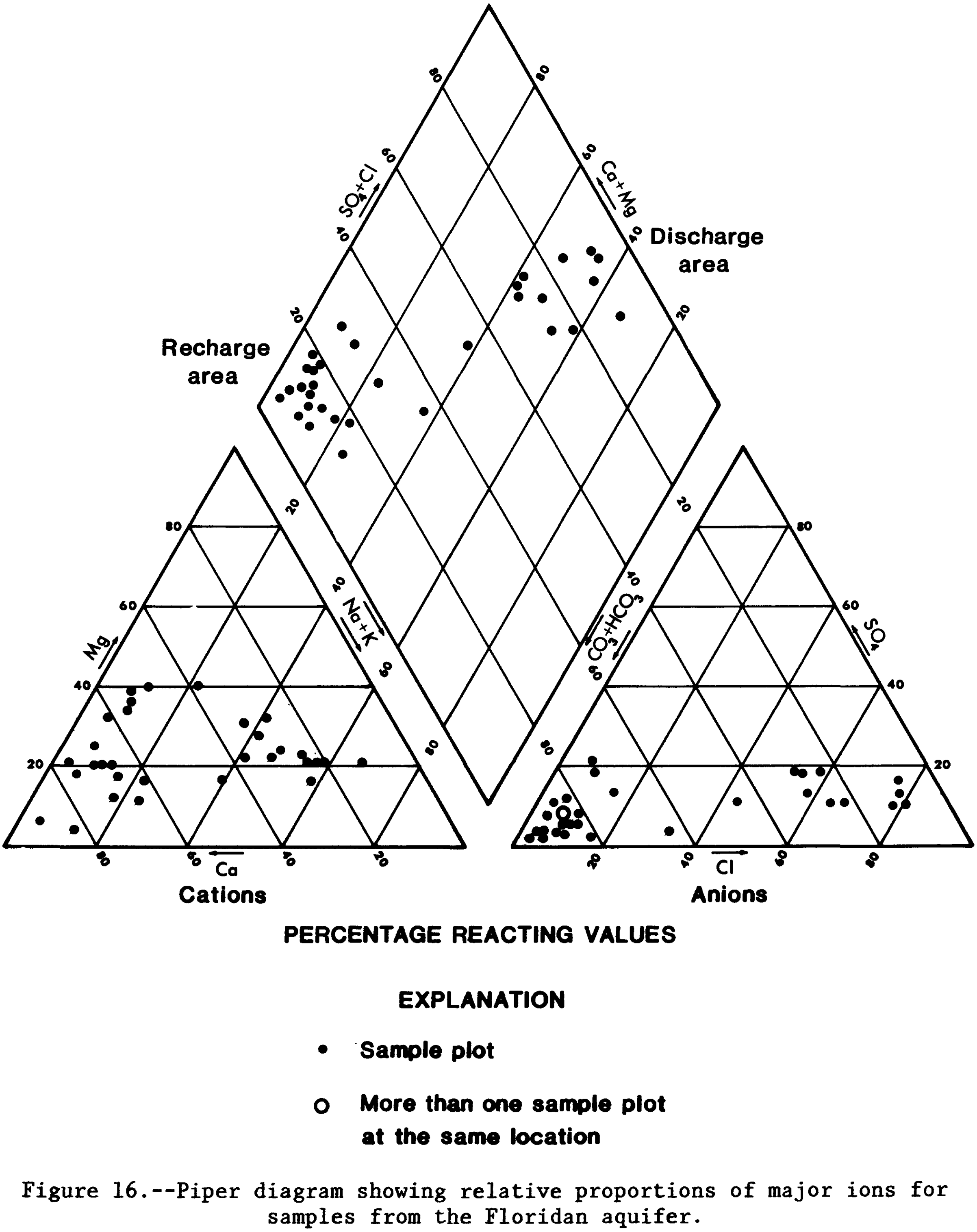


Figure 16.--Piper diagram showing relative proportions of major ions for samples from the Floridan aquifer.

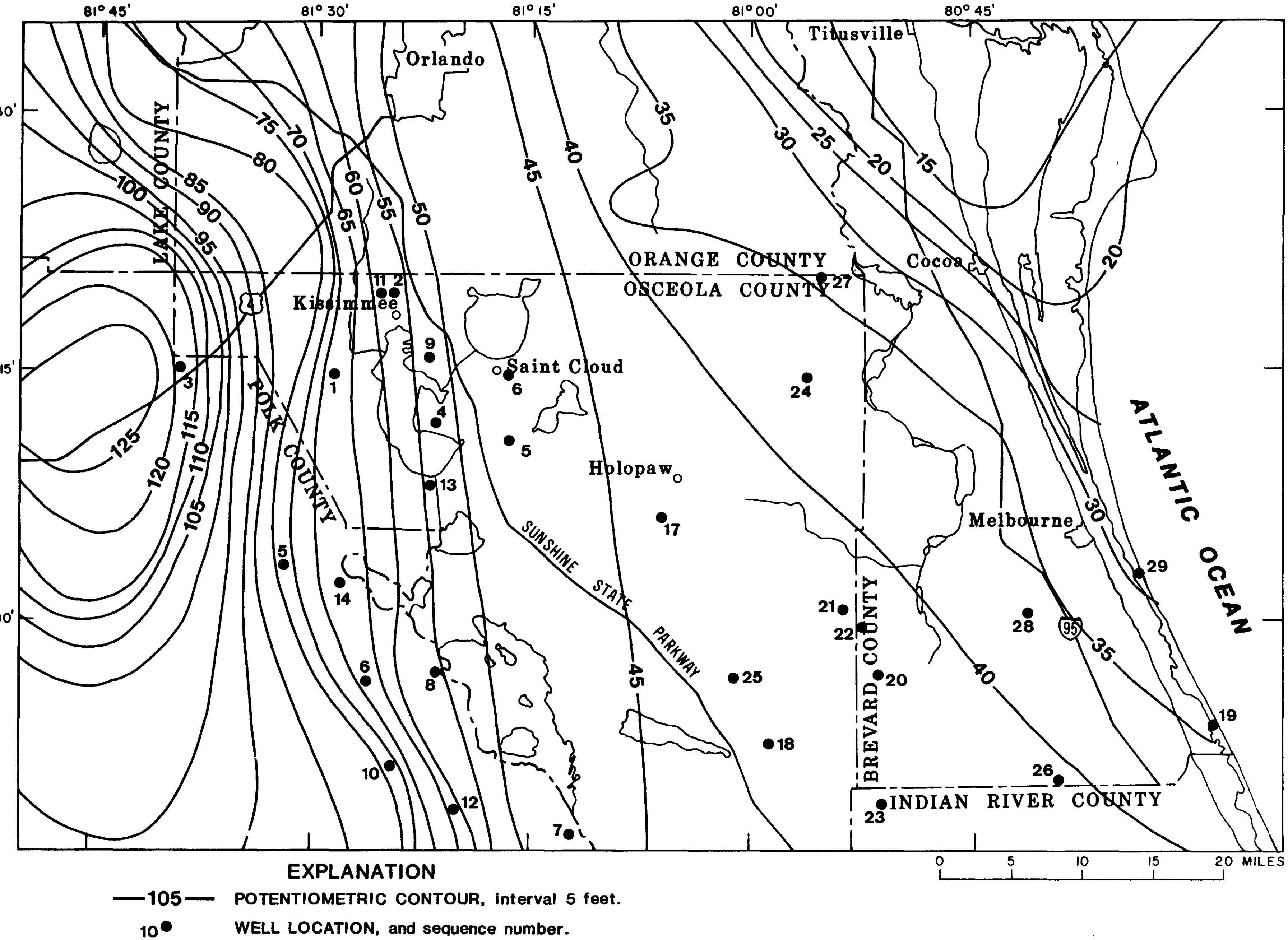


Figure 17.--Ranking of selected wells from the anion triangle of the Piper diagram plotted on the potentiometric surface.

"2. The intermediate zone--with less active ground-water circulation and higher total dissolved solids. Sulfate is normally the dominant anion in this zone.

"3. The lower zone--with very sluggish ground-water flow. Highly soluble minerals are commonly present in this zone because very little ground-water flushing has occurred. High Cl^- concentration and high total dissolved solids are characteristic of this zone."

It is necessary to use data from similarly constructed wells to evaluate the process of anion evolution. Wells that derive water from only one of the zones mentioned above may plot out of sequence on the potentiometric surface map. A good example is the Kissimmee well field where two wells (48 and 47, fig. 3) are 450 feet and 1,195 feet deep, respectively. The quality of the water from each is similar (table 3), except for dissolved sulfate. This difference causes the shallower well (48) to plot as number 2 on the anion triangle and the deeper well (47) to plot as number 11. It can be seen that the first 14 wells to the left are grouped closely together in the anion triangle (fig. 16). Owing to the time span over which the samples were collected for comparison, small changes in concentrations could alter the exact order of plot. The general pattern in figure 17 shows an evolution of anion change in the direction of flow (normal to the potentiometric contours). Numbers higher than 14 are not found upgradient of the 50-foot contour.

Downgradient of the 50-foot contour, two wells plot out of sequence. One (well 20, fig. 3) obtains water from a lower zone (discussed in the section on saline water) and the other (well 7, fig. 3) probably obtains water that is not a part of the regional flow pattern but from an isolated zone in the aquifer that contains fresher water than one would normally expect.

Well 20, which plots as number 25 in figures 16 and 17, is more than 1,100 feet deep and has as least 400 feet of casing. Therefore, the casing is set in the Floridan aquifer instead of in the Hawthorn Formation. This well derives most of its water from the highly transmissive zone below 600 feet that was discussed earlier. Geophysical logs determined that high chloride waters occur at depths lower than 650 feet below land surface, so well 20 could be classified under zone 3 (Domenico, 1972).

The second well (7, fig. 3) to plot out of sequence is number 19 in figures 16 and 17. Well 7 is located in an area where chloride concentrations are anomalously under 250 mg/L. To date there is no substantiated explanation for lower chloride concentrations being found offshore when inland chlorides reach values over 700 mg/L. One theory is that the offshore area of low concentrations is the result of freshwater that entered the aquifer at a time when sea level was much lower; then as sea level rose, a "bubble of fresher water" was trapped against relatively impermeable materials. If this theory is valid, the impermeable materials have trapped this fresher water and isolated it from the regional flow system, so the water in the "bubble" should date older than water from other parts of the flow system. Samples were taken from two lines of three wells for carbon-14 age dating (fig. 18). Each line of three wells was presumed to be on the same general flow path. The northern well (16, fig. 3) along the coast is in an area where chloride concentrations are greater than 500 mg/L. The intention was to compare ages in the two lines of wells on parallel flow paths. If the above explanation is correct--that is that fresher water is trapped in the area of well 7--then water from well 16 should date close to the age of water from the inland wells and younger than water from well 7. Unfortunately, the northern sample along the coast (well 16) was contaminated with water from the surficial materials, probably through leaks in the casing, so the age of the water in the area of higher chloride concentrations offshore remains unknown. The corrected carbon-14 ages for the three southern wells from west to east are 18,000 years (well 3), 21,000 years (well 4), and 29,000 years (well 7). The dates for the three northern wells from west to east are 22,000 years (well 19), 21,000 years (well 18), and less than 2,000 years (well 16).

These carbon-14 ages were corrected assuming a closed system to CO_2 gas and no fractionation between the water and rock materials. From the above, it can be seen that water from well 7 dates older than water samples from the other five wells. A stronger conclusion could be offered if an uncontaminated sample had been attained in well 16 and had that water sample dated within the age range of the other four wells sampled.

Other chemical evidence also may indicate that the area around well 7 is not part of the regional flow system. As water moves down a flow path, the saturation levels of minerals should increase. Comparison of the amount of carbonate saturation for wells sampled in the southern line show that well 3 was slightly undersaturated, well 4 was slightly supersaturated and well 7 was clearly undersaturated (C. L. Sprinkle, U.S. Geological Survey, oral commun., 1982). The percentage of carbonate saturation should increase along a flow path if the physical and chemical properties of the system remain constant. No data exist to indicate a change in the system that would cause carbonate precipitation, so well 7 is apparently not part of the same flow path as the two wells to the west (3 and 4), and is not part of the regional flow pattern. This conclusion may explain the position (number 19) that well 7 plots on the Piper diagram (too young for the location of the well). The chemical character of the water from well 7 places it in an anomalously high bicarbonate range for its position in the flow system. However, carbon-14 dating has placed the age of the water as much older than the inland waters, as one could expect. These data support the theory that the fresher water offshore was trapped as sea level rose and that the water has been isolated from interacting with the present regional flow system. The importance of whether this low chloride area is isolated from the regional flow system is that, if isolated, it is not being recharged and any withdrawal of water would be replaced by water of poorer quality.

Except for the anomalous two wells that plot as sequence numbers 19 and 25 (fig. 17), the pattern of chemical evolution of the ground water conforms to the general pattern of ground-water flow. Low numbers plot in the recharge area, middle numbers plot in the intermediate area, and high numbers plot in the discharge area. There is more of a pattern to the numbers greater than 14, probably due to the tolerance in measurement of

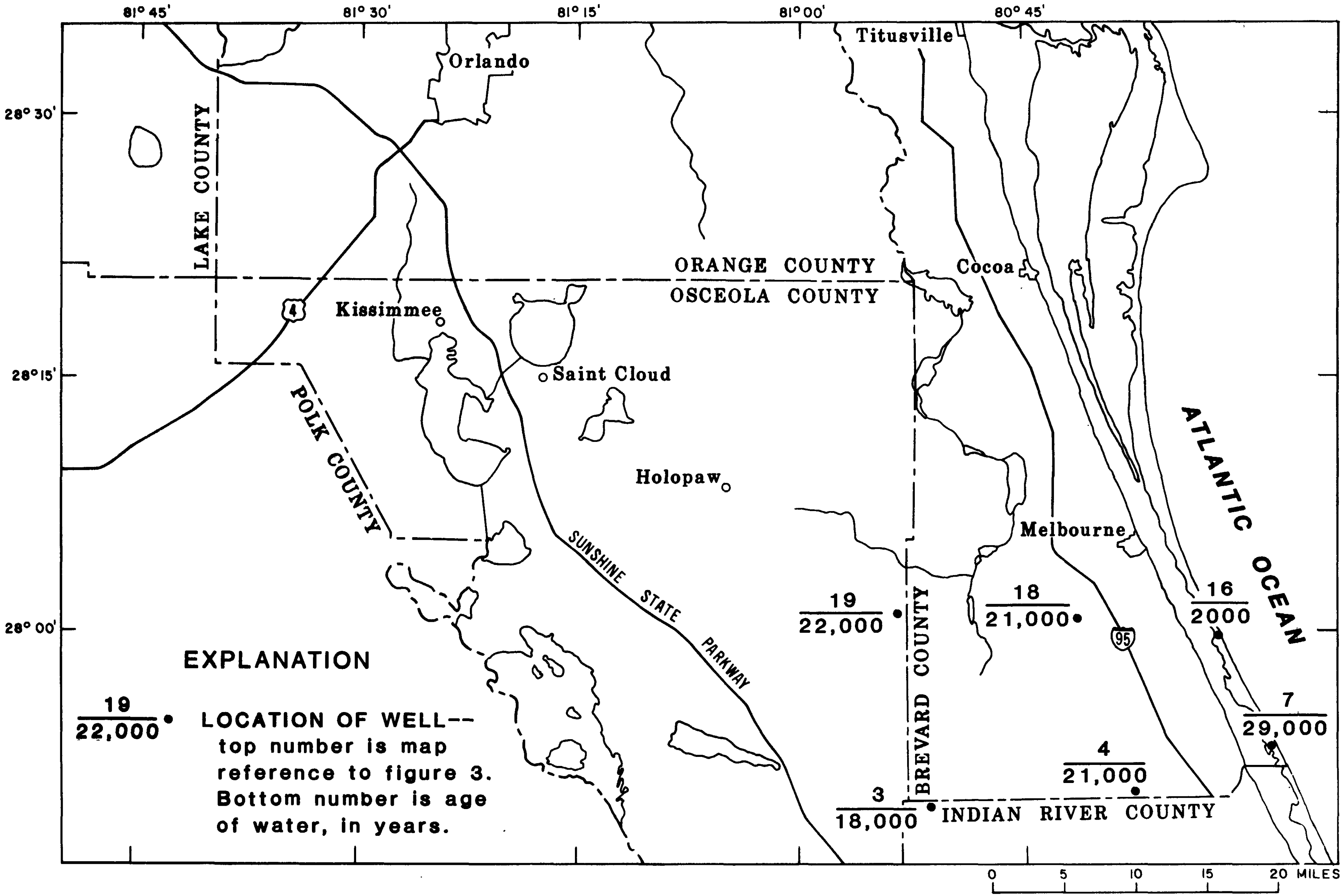


Figure 18.--Location and relative age of wells sampled for carbon-14 dating.

ion concentrations. The low ion concentrations in the recharge area allows relatively minor differences in concentrations to greatly influence the computed percentage values used in the Piper diagram.

Major Ground-Water Pumpage

Five major public water supply systems in the study area obtain water from the Floridan aquifer. Three systems (Cocoa, St. Cloud, and Walt Disney World complex) tap the upper 600 feet of the Floridan. Kissimmee has one of two wells drilled to almost 1,200 feet and the city of Orlando withdraws most of its water from a zone below 1,000 feet. The 1978 yearly average pumpage for each system is as follows:

1. City of Cocoa averages 15 Mgal/d from its well field in eastern Orange County.

2. City of St. Cloud averages 1.1 Mgal/d.

3. City of Kissimmee averages 2.5 Mgal/d.

4. Walt Disney World complex averages 7.5 Mgal/d from two locations--6.7 Mgal/d at the Theme Park and 0.8 Mgal/d at Lake Buena Vista.

5. City of Orlando averages 40 Mgal/d from 7 pumping centers throughout the city.

Figure 19 shows the centers of pumpage for each system.

Water is pumped from the Floridan aquifer to supply other needs--irrigation, industrial, thermoelectric, and rural domestic. In general, the total amount pumped for irrigation is not well documented, is so dispersed that the effect on the potentiometric surface cannot be measured, and is significant mainly on a seasonal basis when rates increase due to dry weather demands.

Data have been compiled as part of the Southeastern Limestone Regional Aquifer study to estimate pumpage for these usages for average-weather and dry-weather conditions (C. H. Tibbals, U.S. Geological Survey, written commun., 1982). Estimates for pumpage other than public supply within this study area are 95 Mgal/d for average weather conditions and 264 Mgal/d for dry weather conditions. These are estimates, however, and there are no criteria to determine a range of validity for the estimates. The dry weather rate was based on estimated water demand for citrus over a period of 60 days. Considering this effect on a steady-state analysis, a yearly rate could be assumed as one-sixth of the 264 Mgal/d, or 44 Mgal/d. Over the 1,000 mi^2 in the study area, this is a rate of about 30 $gal/min/mi^2$; and this does not take into account that some of the water may reenter the ground-water system, or that the seasonal pumpage is supplied mainly from storage that is replenished during the wet season of the year. The estimated average weather rate applies to 6 months of the year and similar reasoning can be applied--that is: without sustained withdrawals for at least one-half of the year, water levels may recover during the wet season as water is stored within the aquifer.

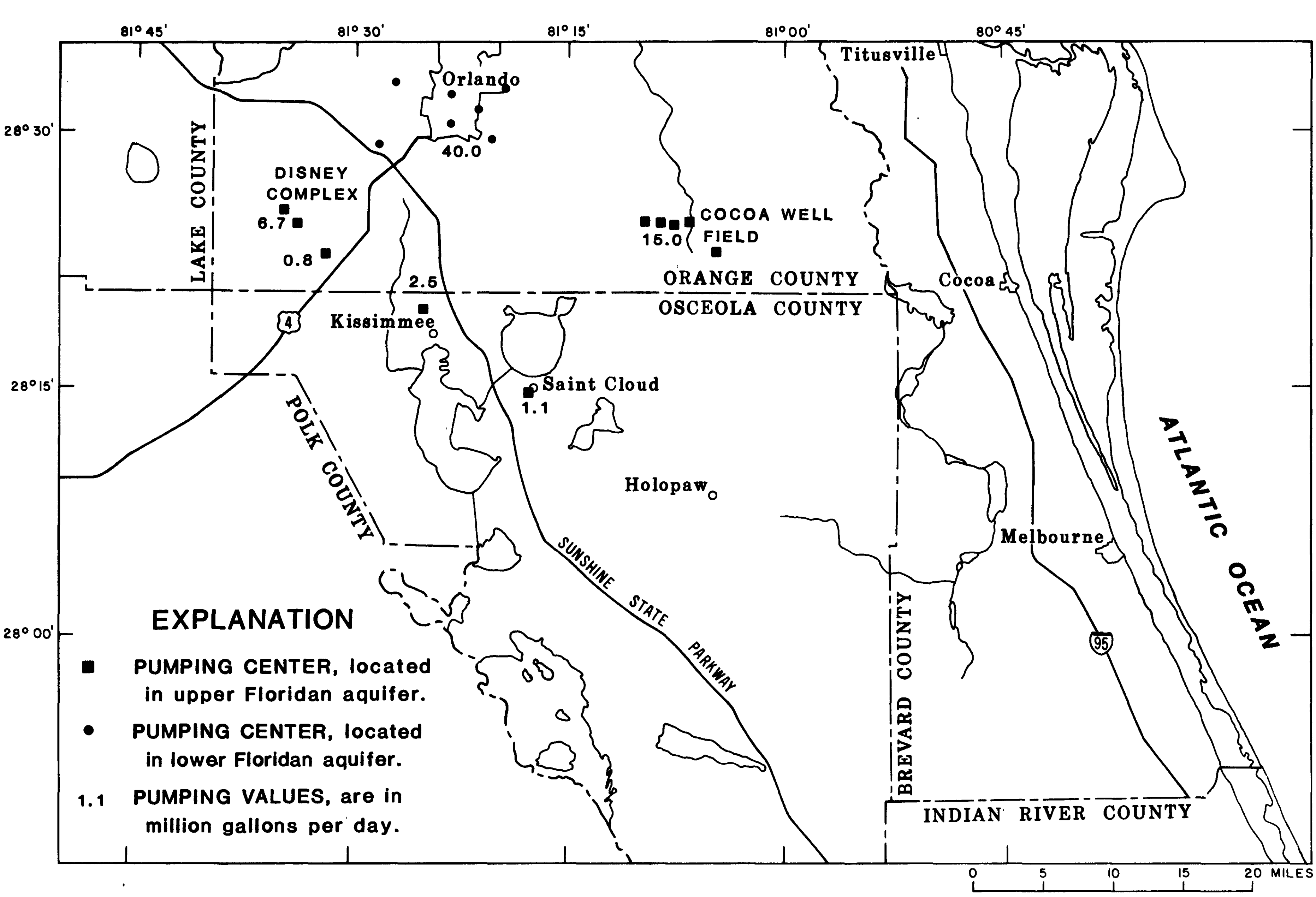


Figure 19.--Location of major ground-water pumpage.

The majority of "other than" public supply pumpage is for irrigation of citrus crops, and the pumpage is concentrated west of the Kissimmee River along the Lake Wales Ridge and in the southeastern corner of Brevard County.

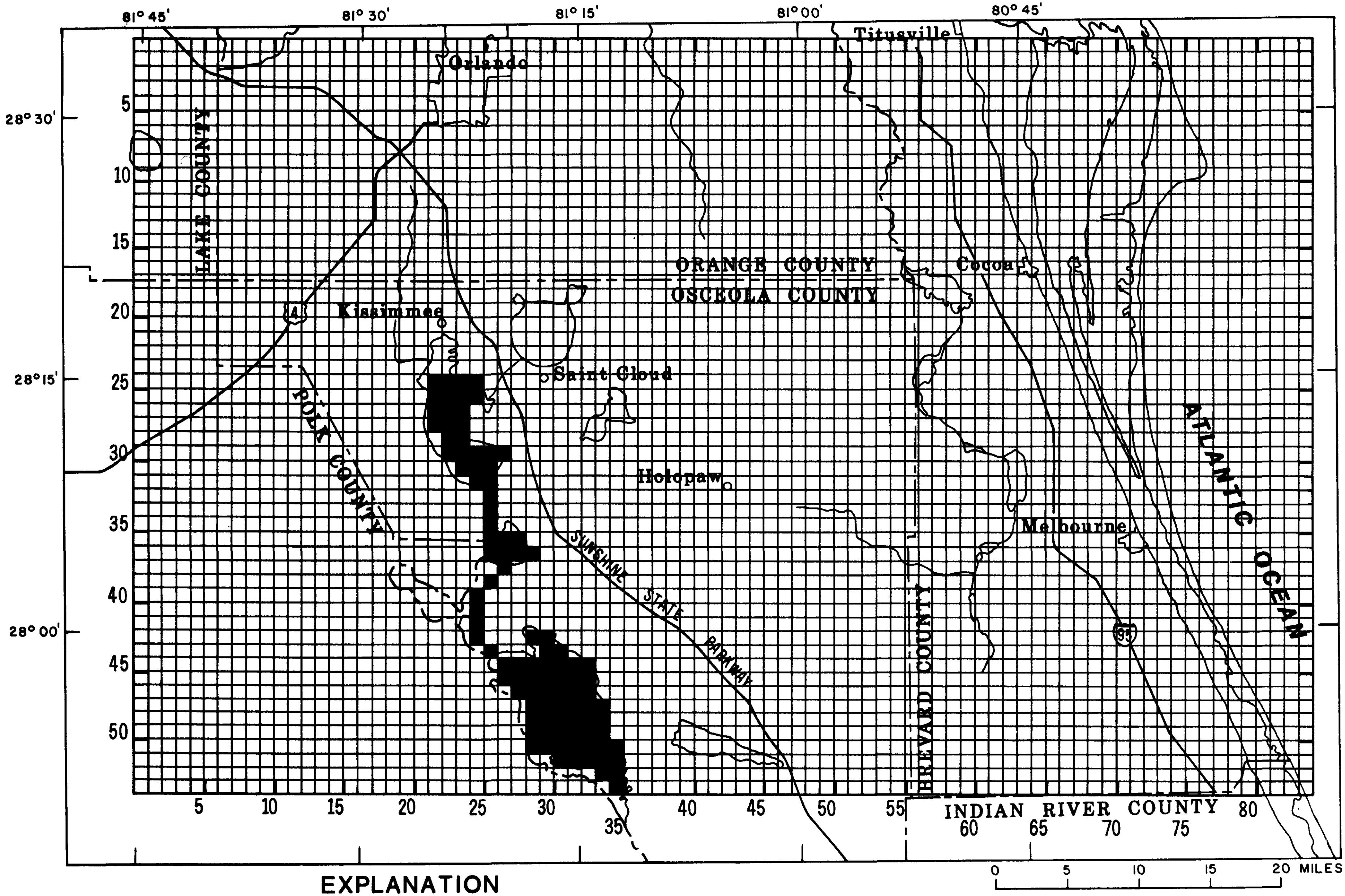
MODELING THE GROUND-WATER SYSTEM

A computer program that simulates quasi-three-dimensional ground-water flow (Trescott, 1975) was used to model the study area. The program uses finite-difference techniques to solve the ground-water flow equation for three-dimensional, steady or nonsteady flow in an anisotropic, heterogeneous ground-water system. Finite-difference techniques require that the ground-water system be divided into rectangular blocks and that average values of each parameter in the flow equation be assigned to every block in the finite-difference grid. The grid used for the study is shown in figure 20; it has dimensions of 54 blocks in a north-south direction and 84 blocks in an east-west direction. Each block is square with a side length of 1 mile.

Model Construction

The model was constructed to evaluate a steady-state system using data from September 1980; therefore, no parameter values were needed for specific yield of the surficial aquifer or the storage coefficients of the Floridan aquifer and confining layer. The system was considered to be at steady-state from May to September 1980 because head measurements made at these two times changed less than a foot on the average over the study area. Information from three continuous water-level recorders (map numbers 43, 51, and 53; fig. 3) confirmed that levels in the wells fluctuated roughly less than a foot between the two measurement periods of May 10-17, 1980 and September 8-18, 1980 (fig. 21). Hydrographs for these three wells are considered representative of aquifer conditions throughout the study area. After September 1980, severe drought conditions prevailed through the remaining period of data collection for the study, water levels in many wells reached record lows, and the system cannot be considered at steady-state.

The model consists of five units: (1) a surficial aquifer, (2) an upper confining layer, (3) an upper flow layer that represents the upper 500 feet of the Floridan aquifer, (4) a confining layer that represents the vertical resistance to flow in the Floridan aquifer, and (5) a lower flow layer that represents another 500 feet of the Floridan aquifer (fig. 22). The type of simulation used for the analysis is termed quasi-three dimensional, because lateral flows in the aquifers are modeled (active layer), but only vertical flow through the confining layer is modeled (inactive layer). Initially, the surficial aquifer was modeled as an active layer, but many adjustments had to be made without supporting data. The variability in thickness and composition of surficial aquifer materials restricted firm estimates of transmissivity. The marine environment of deposition of the surficial aquifer tends not to produce a laterally continuous water-table aquifer. Streamflow data were poor due to regulation of the Kissimmee and St. Johns Rivers and could not be used to determine the contribution of ground water to the rivers. Therefore, modeling the surficial aquifer as



EXPLANATION

■ Block where vertical hydraulic conductivity was greatly increased during calibration

Figure 20.--Horizontal finite-difference grid used in the model.

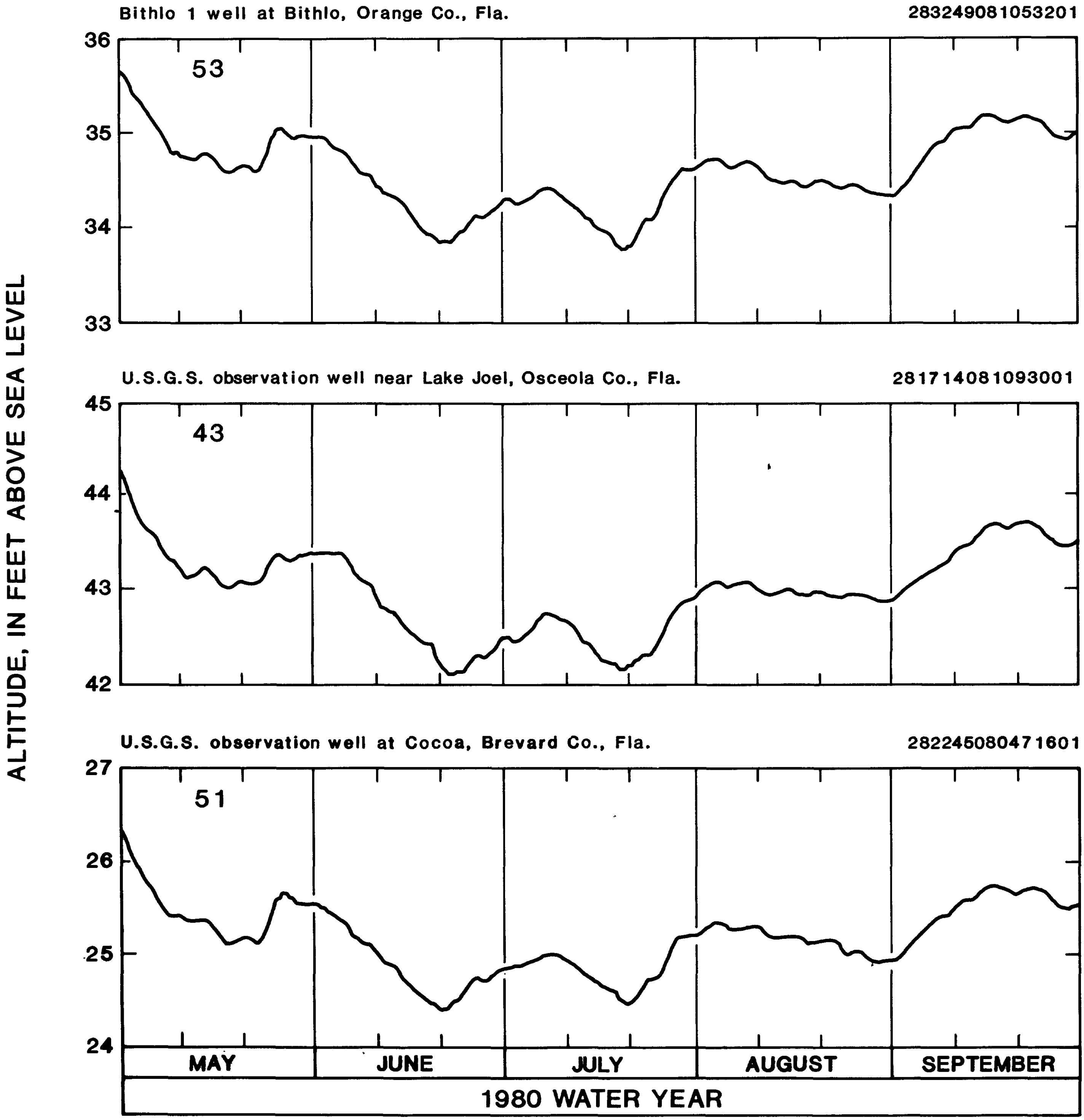


Figure 21.--Hydrographs of wells showing that steady-state conditions were approached in the Floridan aquifer for the time period used for calibration.

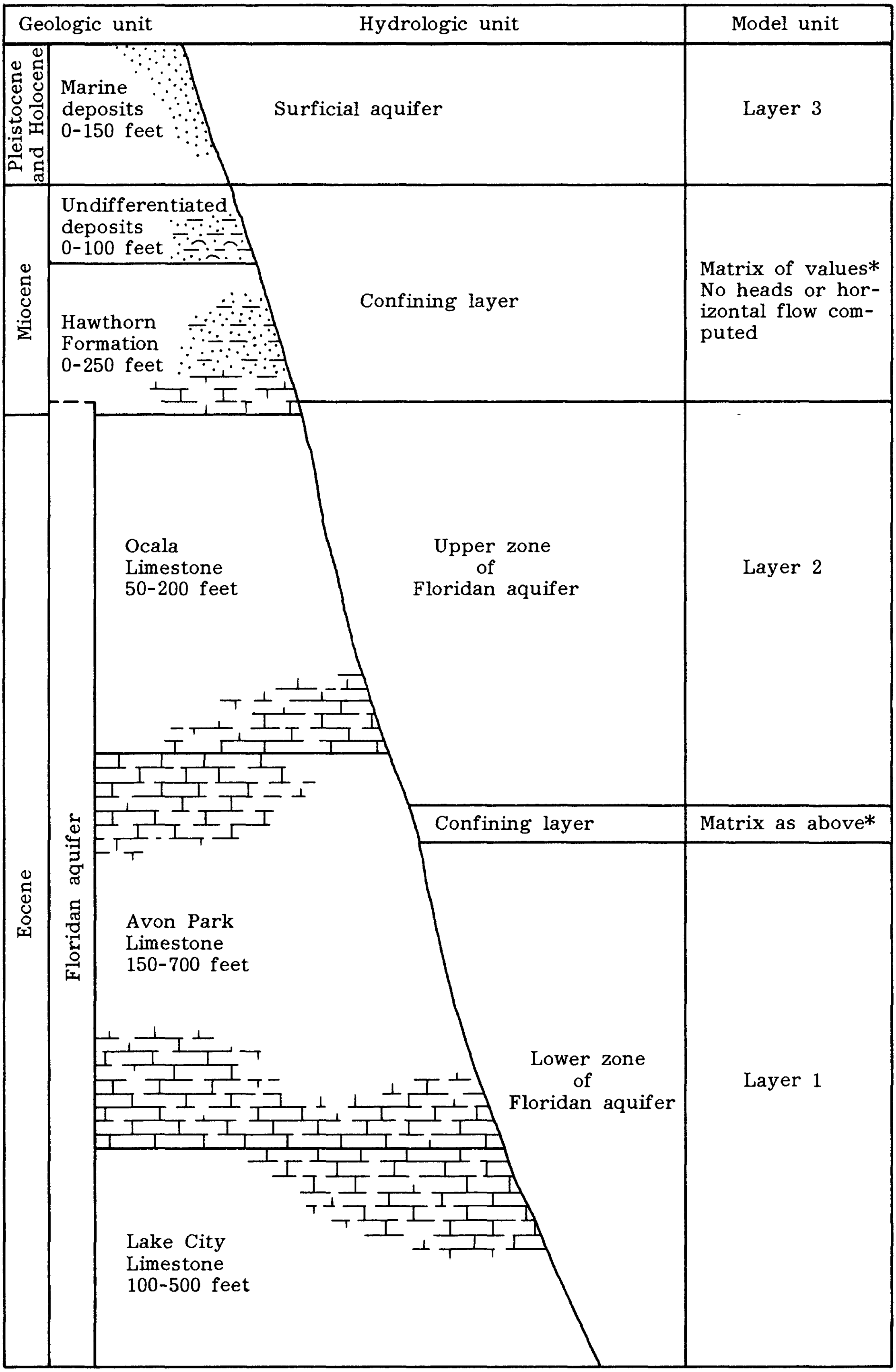


Figure 22.--Sketch showing geologic units, hydrologic units, and model units.

an active layer was abandoned, and heads that correspond to the water table were input to the model and held constant to represent the surficial aquifer and interaction of the streams with the Floridan aquifer.

The exchange of water between the surficial and the Floridan aquifers is controlled by the confining layer. Because the confining layer is composed mostly of clay and clayey materials, the amount of horizontal ground-water flow is thought to be negligible, so the unit was not modeled as an active layer. The thickness (b) of the unit (fig. 6) and the vertical hydraulic conductivity (K') of 0.005 ft/d determined from the shallow aquifer tests were used to calculate a leakance value (K'/b) for each block. Leakance values were input as a data matrix and the value plus the difference in head values between the surficial and Floridan aquifers were used by the program to compute the amount of water exchanged between the units.

The Floridan aquifer was simulated as two layers, each 500 feet thick. Two layers were necessary because pumpage in Orlando indicates that there are two zones in the Floridan aquifer. (Pumpage from the deeper zone has no discernible effect on shallower wells in the Orlando area.) The lower layer could provide a source of upward leakage for the experimental pumping runs, as the depths of the wells as designed in the model did not penetrate the aquifer to its base. Transmissivities were calculated using the average hydraulic conductivity of 65 ft/d obtained in the specific capacity analysis. The initial transmissivity distribution was a uniform value of 32,500 ft^2/d for each layer.

The vertical resistance to ground-water flow is generally greater than the horizontal resistance for most materials. Because the limestone was modeled as two layers, the connection between the layers must be modeled with a leakance matrix of vertical hydraulic conductivity divided by thickness (K_z/b). Information on the vertical hydraulic conductivity of the limestone was available from reports by Pride and others (1966), and Tibbals (1975). The reported values were determined from laboratory analyses of core samples taken outside the study area in the Green Swamp area and along the Summit reach of the Cross-Florida Barge Canal. Seventeen values are available from the two studies. The range of K_h/K_z was 0.09 to 30, and the average value for the ratio was nearly 4. It should be noted that the samples from the Summit reach area were taken at shallow depths where exposure to weathering probably increased the vertical hydraulic conductivity for the section tested. To be conservative, the authors chose a ratio of 10:1 for horizontal to vertical hydraulic conductivity, resulting in a value of 6.5 ft/d for the vertical conductivity of the limestone. The thickness used in the calculations was 500 feet because the heads calculated for the model are referenced to the vertical center of the grid block which would place the heads 500 feet apart when modeling 1,000 feet of limestone. The resulting leakance value was 0.013 d^{-1} and was held uniform for the entire grid.

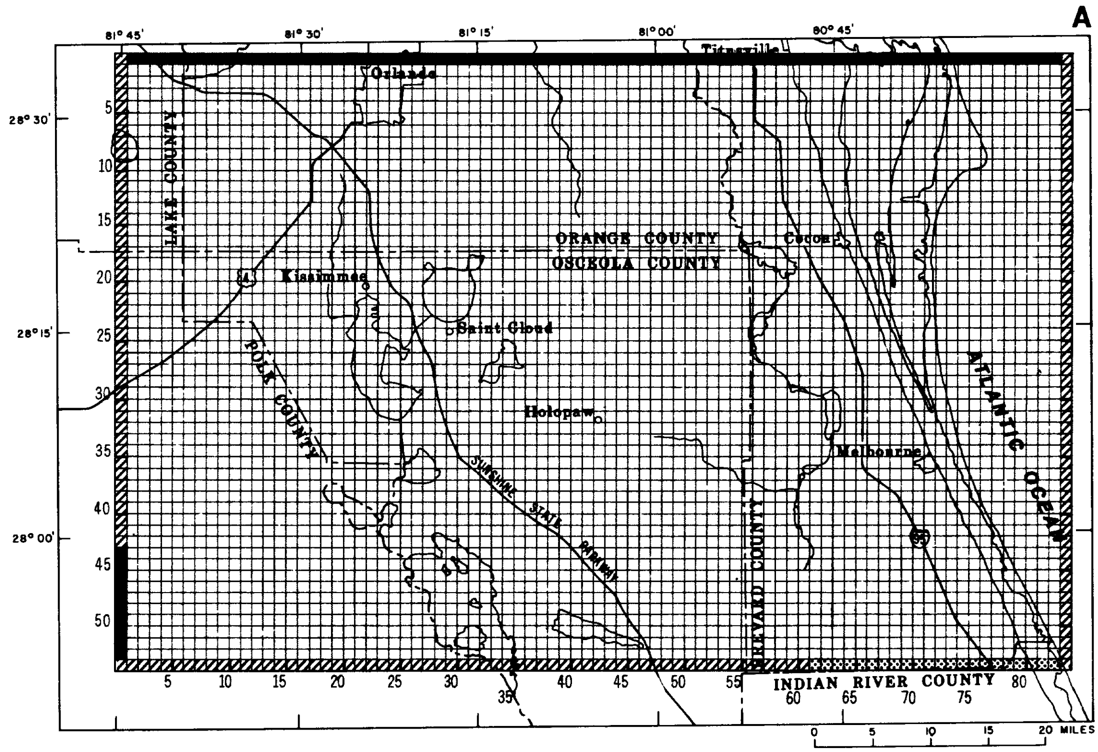
Few projects can incorporate the entire aquifer into a model, so boundary conditions must be chosen to maintain the proper flow pattern for the part of the aquifer system modeled. The optimum choice is to select boundaries that would be unaffected by the simulated stresses. However, late in the project, one viable alternative being considered for Melbourne's supply was to increase the pumpage of the Cocoa well field in Orange County and to interconnect the two distribution systems. There was no time to expand the boundaries the necessary distance that would render the northern boundary unaffected by pumping. Consequently, boundary conditions were chosen that approximate a continuance of the aquifer system to a point of recharge or discharge or to a point beyond the influence of the proposed pumping.

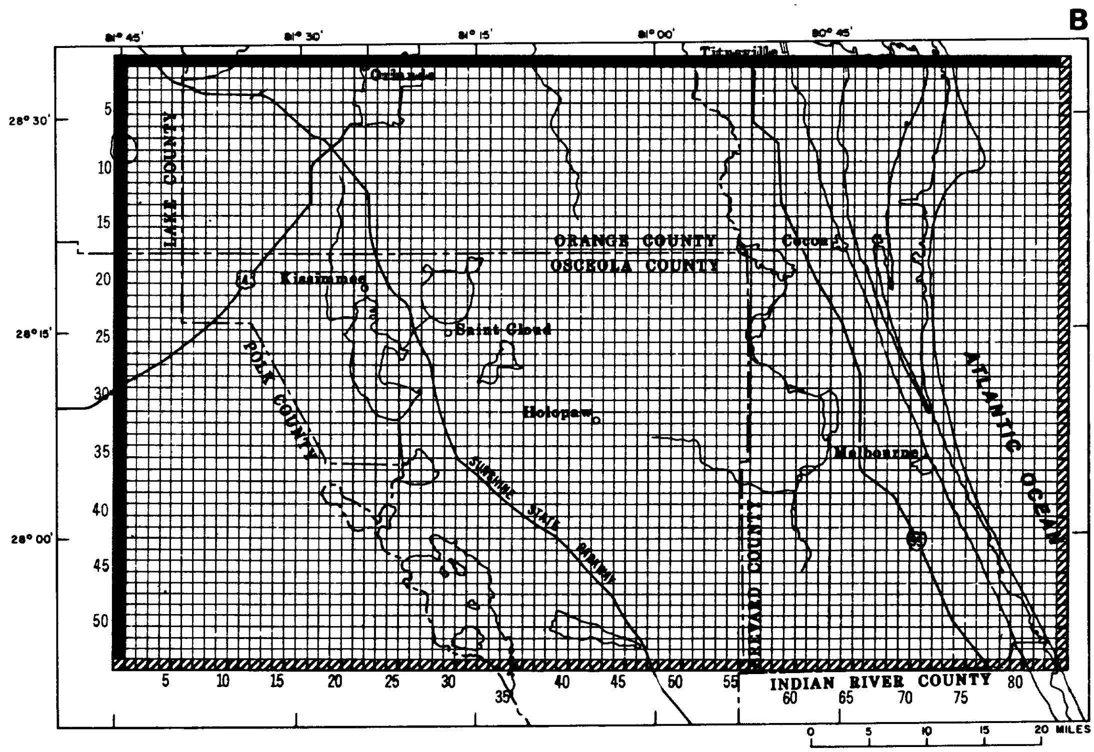
The western boundary was chosen so the potentiometric surface high for the system could be incorporated into the model. The potentiometric surface high could normally be treated as a no-flow boundary at a line drawn to show the divide between ground water moving to the east or west. But early model runs with a simplified ground-water system indicated that pumping effects in central Osceola County may lower heads in the region, thus changing the position of the divide. The boundary condition used for this border was head-controlled flux where flow across the border is determined from a point outside the model that can be assumed to remain constant throughout the simulations (fig. 23). Information needed to determine the flow at a head-controlled flux boundary includes transmissivity of the aquifer beyond the boundary, distance to the controlling head, and the controlling head. The average head in the aquifer at a distance of 20 miles from the western boundary was 50 feet, and the transmissivity was assumed to be at constant 32,500 ft^2/d. The head-controlled flux boundary was placed in the lower layer because the pumpage for Orlando is located in the lower layer close to the northwest corner of the model. The relatively high vertical hydraulic conductivity between the limestone layers will allow a head-controlled flux condition to control both layers. Therefore, most of the western boundary for the upper limestone layer was modeled as no-flow and the western boundary for the lower layer was modeled as head-controlled flux.

The eastern boundary was the most difficult to classify because of the lack of data offshore of northern Brevard County. Head data for the eastern edge indicates water is flowing westward from offshore to be discharged under the Indian River. However, extrapolating the 25-, 30-, and 35-foot contours offshore, nearly 50 percent of the border to the south would have the potentiometric contours intersect the border at right angles, allowing the use of a no-flow boundary. Without knowledge of the actual heads offshore or the distance to the end of the aquifer, the authors felt that use of a no-flow boundary would give the most conservative estimates for the pumping runs, as drawdowns would be maximized in the direction of water with higher concentrations of chloride.

Using the map of the potentiometric surface (fig. 8) as a guide, it can be seen that most contours intersect the southern edge of the model at an angle of nearly 90°. This indicates that the flow is parallel to the edge, water is neither moving into nor out of the modeled area along this border, and a no-flow boundary may be used.

Head gradients indicate flow across the northern border, and the regional flow pattern shows that the St. Johns River system is the controlling factor. A head-controlled flux boundary was used for the northern boundary of each layer. In the upper layer, this involved selecting the head at a point of discharge (St. Johns River, Wekiva River, and so forth; fig. 1) for the aquifer,





EXPLANATION

- NO FLOW BOUNDARY
- CONSTANT HEAD BOUNDARY
- HEAD-CONTROLED FLUX BOUNDARY

Figure 23.--Boundary conditions for calibrated model, (a) upper layer, and (b) lower layer.

and determining the distance to the point of discharge, the transmissivity of the layer, and the vertical connection between the aquifer and the point of discharge. The lower layer had a head-controlled flux boundary that corresponded to a head in the layer at a distance of 20 miles with the head determined at that distance from the potentiometric surface of September 1980. The high vertical hydraulic conductivity between the two layers should allow the boundary in the upper layer to exert the maximum control, as the distance to the river system is less than 20 miles.

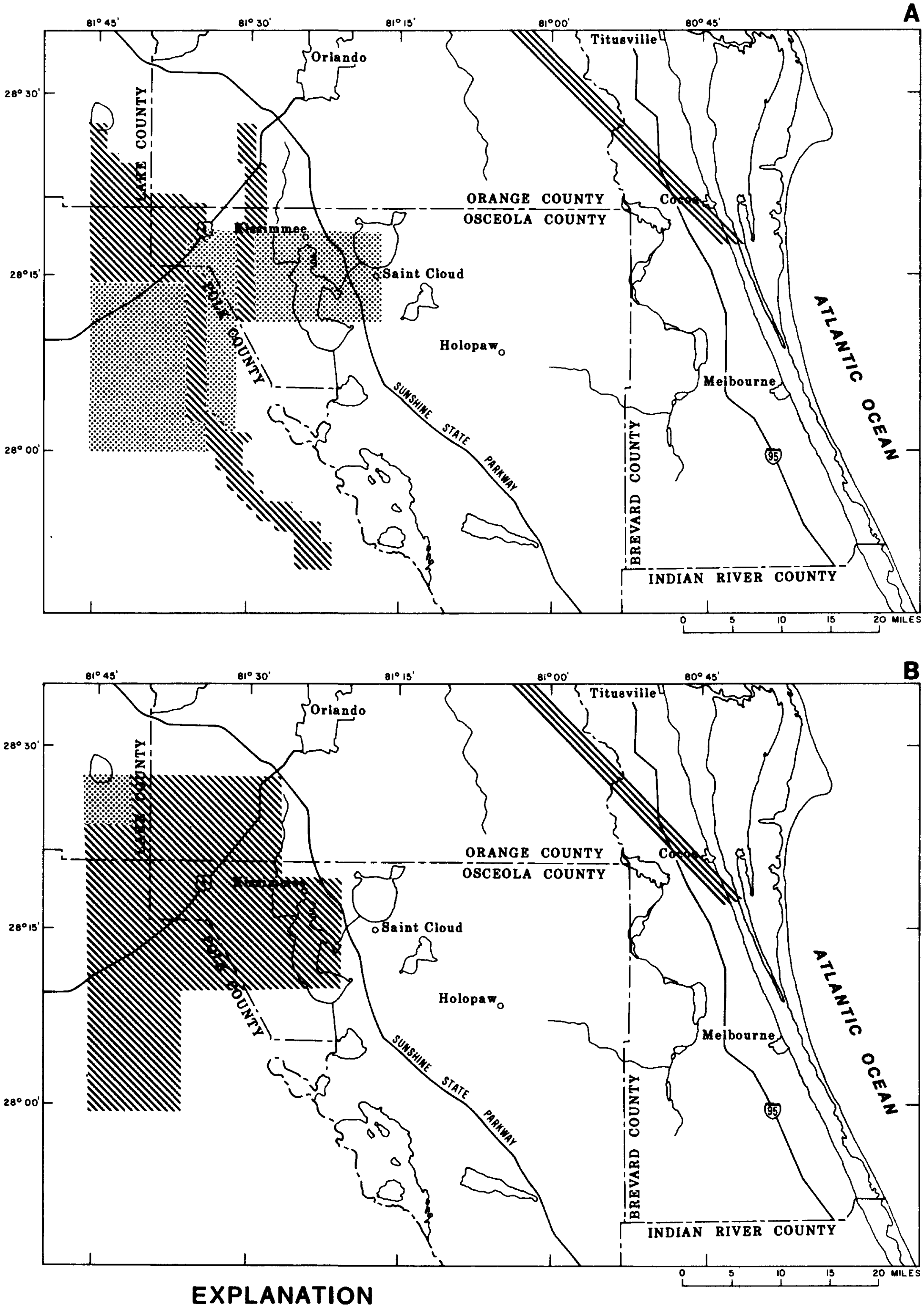
The base of the model below 1,000 feet of limestone is considered to be impermeable. Data have shown that less permeable zones exist at depth in the Floridan aquifer. The proposed pumping will be from the upper limestone layer, so the lower layer will represent the remainder of the aquifer. The use of two layers for the Floridan aquifer can be thought of as moving the vertical boundary beyond severe effects from the simulated pumping.

Ground-water pumpage of the major suppliers shown in figure 20 was included in the model. The yearly pumpage rates have remained fairly stable since 1977 with Orlando and Kissimmee having the maximum increases of about 10 percent. Therefore, the heads around the pumping centers have probably stabilized and the system can be assumed to be under steady-state conditions. During early model runs, only Cocoa and Orlando pumpage were included in the model, mainly because of the large quantity pumped from each source and because the effect of Cocoa's pumping is clearly seen on the potentiometric surface. After several unsuccessful adjustments to other parameters, it was evident that some other factor not included in the model prevented the lowering of heads in the upper reaches of the Kissimmee River system. The other public supplies (Walt Disney World complex, Kissimmee, and St. Cloud) were then included in the model and the effect was to lower the heads within the criteria for a match.

Model Calibration

The model was calibrated to hydrologic conditions of September 1980. Water levels from nearly all 114 wells in the upper layer of the Floridan aquifer were matched with the model to within 5 feet of the measured values. In order to obtain a match, the following parameters were adjusted: transmissivities in both layers and leakance values for the confining layer, plus the addition of two boundary conditions (head-controlled flux in the southwestern corner, and constant head nodes in the southeastern corner).

The potentiometric surface map suggests that the distribution of transmissivity is not uniform. The steep gradients in the western part of the study area indicate low transmissivities which were corroborated. Changes only to the upper Floridan layer were attempted first, but changes were also made to the lower Floridan layer. Transmissivity over large areas was changed first, then as the adjustment of other parameters did not produce the desired results, refinements were made in detail. Reducing the transmissivity in the west provided the gradients that were needed, but the actual heads produced were too low. It was necessary to double the transmissivity throughout both layers to raise heads to acceptable values. The final transmissivity distributions for both layers are shown in figure 24.



EXPLANATION

Transmissivity (square feet per day)

- 65,000
- 32,500
- 6500

Figure 24.--Transmissivity distributions from the calibrated model for the two limestone layers, (a) upper layer, and (b) lower layer.

Major changes to leakance values of the upper confining bed were necessary to lower heads along certain stream reaches. Leakance values were raised as much as three orders of magnitude beneath the Kissimmee River and one order of magnitude under the upper reaches of the St. Johns River. The leakance also was increased an order of magnitude under the Indian River where the potentiometric surface has its lowest level.

The leakance values for the upper confining bed had to be lowered one order of magnitude on the eastern end of the model. Heads remained 15 feet low throughout the St. Johns River valley until the change was made. The westward limit for the change roughly coincides with the Pamlico Scarp which suggests that the difference in leakage values may be due to depositional features (fig. 25).

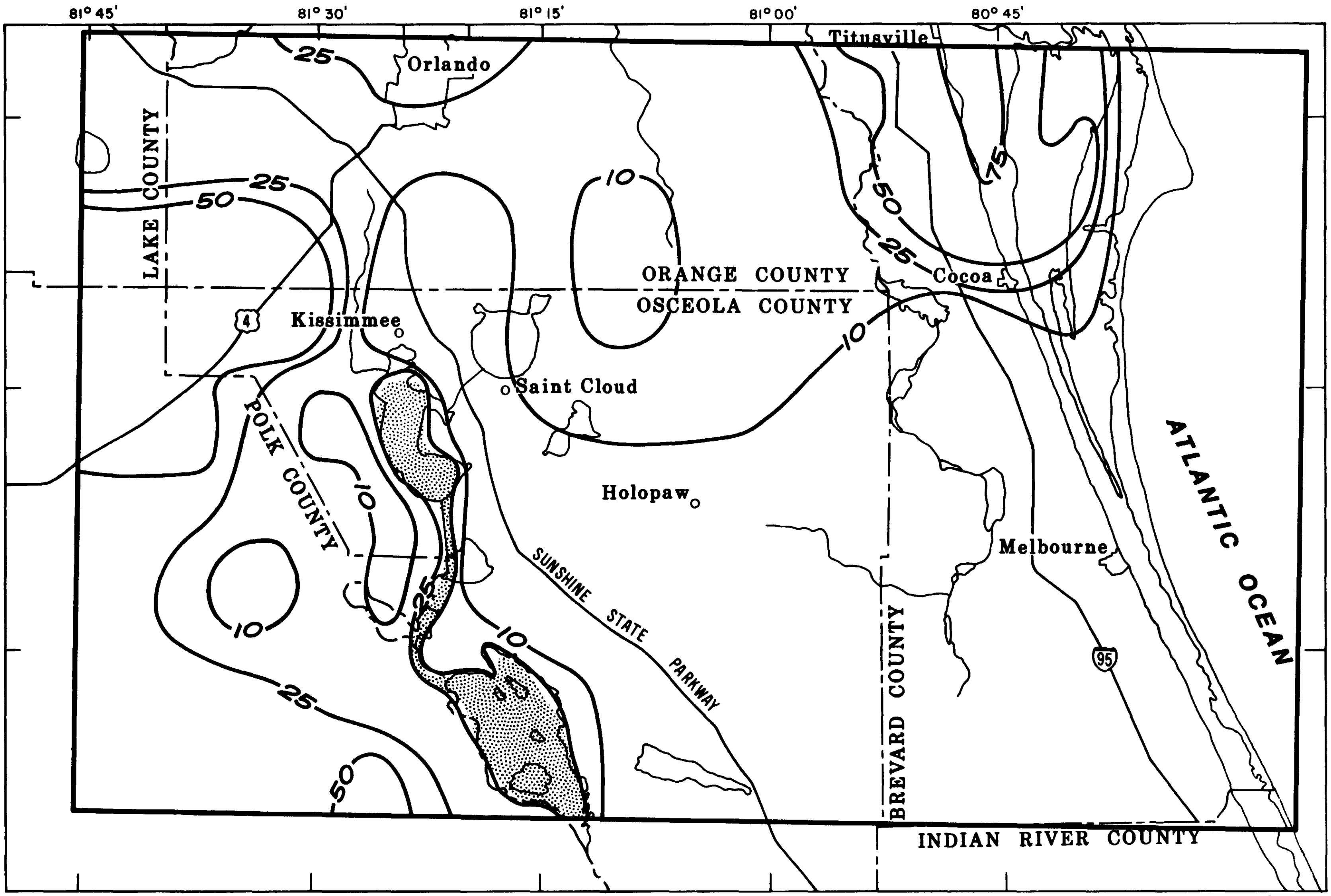
After the described adjustments were made, two problem areas remained--the southwest corner had heads that were about 15 feet too high and the southeast corner had heads that were about 10 feet too low. Pumpage for phosphate mining near Bartow in Polk County had not been introduced. A head-controlled flux condition was added along the southernmost 10 miles of the western boundary to represent the outflow to supply the pumping. In the southeast corner, the potentiometric contours are not perpendicular to the southern border, so for the last 23 blocks along the southern boundary, the heads were held constant in the upper limestone layer allowing inflow of almost 10 ft^3/s from the south.

The potentiometric surface calculated for the upper limestone layer is shown in a contour map with 5-foot intervals, and points where heads were measured are plotted on the map for comparison in figure 26. For more than 60 percent of the measured heads, the calculated water level was within 2 feet. Only 2 of the 114 points of measurement had more than a 5-foot difference between the measured and calculated heads--one 6 feet and the other 8 feet. Neither well had been leveled, so the altitude of land surface as ascertained from 5-foot contour maps could cause the discrepancy. These discrepancies are in isolated areas and should not influence the analysis.

Figure 27 shows model-calculated recharge rates through the upper confining layer to the Floridan aquifer. Highest rates occur in Polk County along the Lake Wales Ridge. The area beneath the Kissimmee River shows large rates of discharge and agrees with similar findings of a model prepared by Tibbals (1981) for the Southeastern Limestone RASA study. The area of the Osceola Plain receives moderate amounts of recharge (1 to 2 inches). Once inside Brevard County, the Floridan aquifer is discharging with rates generally less than 1 inch per year but up to 10 inches per year beneath the Indian River. Along the Atlantic Coastal Ridge in northern Brevard County, there is downward recharge with rates up to 5 inches per year (fig. 27).

Sensitivity Analysis

The final result of model calibration is a definition of the aquifer system that incorporates a blend of known and unknown parameter values. Starting with more than one unknown parameter, the solution can never be



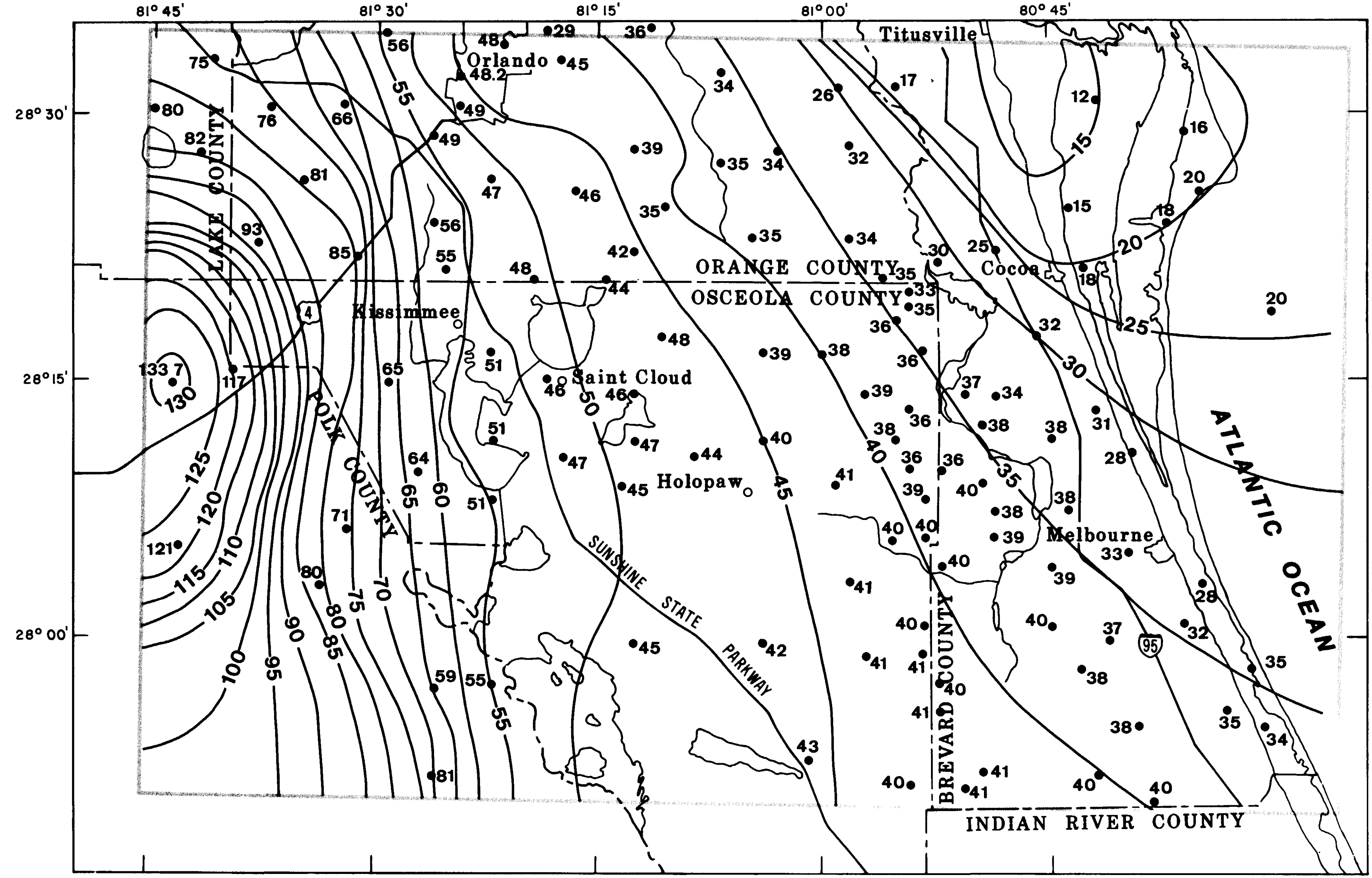
EXPLANATION

—50— LINE OF EQUAL LEAKANCE--in $days^{-1}$,$\times 10^{-6}$. interval 10, 15, and 25.

AREA BENEATH KISSIMMEE RIVER--leakance values are $2.6\times10^{-3} days^{-1}$.

MODEL BOUNDARY

Figure 25.--Leakance values for the confining layer from the calibrated model.



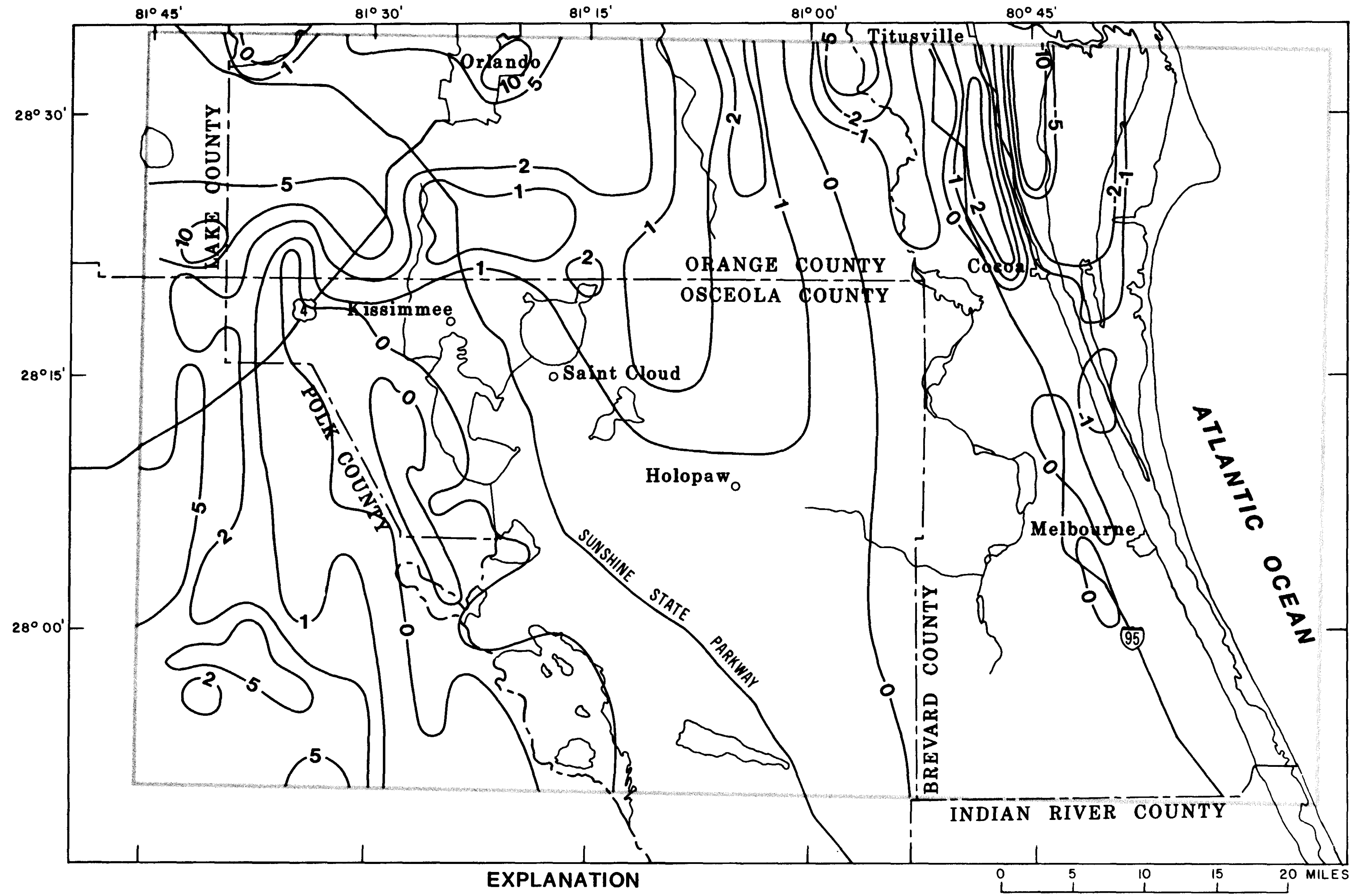
EXPLANATION

—95— MODEL DERIVED POTENTIOMETRIC CONTOUR, shows elevation at which water levels would have stood in tightly cased wells.

•81 WELL AND MEASURED WATER LEVEL, number is altitude of water level above sea level.

MODEL BOUNDARY

Figure 26.--Comparison of model-derived potentiometric surface with measured water levels in upper Floridan aquifer system, September 1980.



EXPLANATION

—5— LINE OF EQUAL RECHARGE OR DISCHARGE (-). Contour interval 1,3, and 5 inches per year. Discharge to the Kissimmee River, in the area shown in figure 20, averaged 14 inches per year.

MODEL BOUNDARY

Figure 27.--Model-derived rate of recharge or discharge, in inches per year, to the Floridan aquifer system through the confining layer.

considered unique. Varying each parameter over its probable value range determines which parameters are the most sensitive to the model, and, therefore, which parameters should be best defined.

Table 4 lists the changes made to the parameter values, the results of the changes on the boundary flows and flow of the Kissimmee River, and the effect on the match between calculated and measured heads. Most changes had minor effects on the model output except for changes in leakance values of the confining layer.

Table 4.--Change in values for sources in the model as a result of testing parameter sensitivity

[T = transmissivity of limestone layer, TB = tranmissivity of limestone beyond border, KZ = vertical hydraulic conductivity of limestone for layer 1 (lower Floridan) and confining bed for layer 2 (upper Floridan), SCF = vertical hydraulic conductivity of Hawthorn Formation beneath Kissimmee River]

Parameter change tested	Layer 1 Boundaries North (ft^3/s)	Layer 1 Boundaries West (ft^3/s)	Layer 2 Boundaries North (ft^3/s)	Layer 2 Boundaries West (ft^3/s)	Kissimmee River (ft^3/s)	Downward leakage from layer 3 to layer 2 (ft^3/s)	Upward leakage to layer 3 from layer 2 (ft^3/s)	No. of blocks where calculated head minus measured head exceeded 5 feet
CAL	23.66	-8.90	-63.26	-7.27	91	365	202	3
T1*0.75	23.63	-9.20	-63.95	-7.15	83	333	194	6
T1*1.25	22.28	-8.93	-65.8	-5.20	94	353	214	5
T2x0.75	23.77	-9.18	-63.02	-6.56	82	331	194	6
T2x1.25	22.15	-8.81	-66.63	-5.73	94	355	215	3
TB1x0.75	17.83	-6.88	-64.97	-6.22	88	343	201	5
TB1*1.25	27.81	-11.31	-65.02	-6.07	89	345	208	4
TB2x0.75	21.06	-9.18	-52.69	-4.99	90	336	208	7
TB2x1.25	24.41	-8.95	-75.62	-7.10	87	351	202	3
KZ1x0.1	21.68	-8.61	-63.77	-6.64	78	330	189	4
KZ1x10	23.54	-9.10	-65.76	-6.05	92	348	208	4
[1]KZ2x0.5	---	---	---	---	---	---	---	42
KZ2x10	7.08	-12.56	-117.17	-19.79	203	1,052	825	78
SCF*0.1	22.46	-9.12	-65.90	-6.97	50	319	170	19
SCF*10	11.24	-9.02	-63.86	-5.90	92	355	218	2

[1] Did not converge after 200 iterations, values are not comparable to other tests.

The tests to determine the vertical hydraulic conductivity of the clay materials of the uppermost confining layer produced values which differed by one order of magnitude, so that range was tested. In both attempts to alter the matrix of values that represent the confining layer, unacceptable results were obtained. Raising the values one order of magnitude brought the heads in the limestone layers very close to the constant heads of the surficial layer. Only 36 of the 114 measurements remained within the 5-foot limit for a match. Testing the values at an order of magnitude lower did not work; the problem did not come to a solution on the computer within the allotted time. A change of one-half an order of magnitude was then attempted at double the time. Again a solution was not obtained; a solution required the heads not to change more than 0.01 foot for any one block between calculations. After 200 calculations, the maximum head change between each calculation was 0.7 foot. The 0.01-foot limit is strictly a mathematical control to assure the calculated heads are accurate. That the change for consecutive calculations was less than a foot should suffice for a test of the value. Forty-two values of calculated head did not match the measured heads.

The hydraulic connection between the upper Floridan aquifer and the Kissimmee River was sensitive because it depends on the vertical hydraulic conductivity of the confining layer. During calibration, it was found that the leakance values under most of Kissimmee River had to be increased nearly three orders of magnitude (fig. 20). Lowering these calibrated values by an order of magnitude put 19 heads out of bounds and reduced the discharge from the aquifer to the river from 91 ft^3/s to 51 ft^3/s. Raising these values one order of magnitude had little effect. Only two heads were out of bounds and the discharge changed from 91 to 93 ft^3/s. Although only two heads are out of bounds for the increased hydraulic connection between the river and the aquifer, the value of leakance was left at the calibration value in case, during a pumping evaluation, the heads in the limestone aquifer were lowered to the point they were below the level of the river. The lower value from calibration will allow less water to enter the aquifer if the gradient were reversed, and this will provide conservative results from the model.

The last "parameter" to be tested is the exclusion in the calibration process of pumpage for irrigation, industry, thermoelectric, and rural domestic uses. For the probable area where new well fields might be located, the expected pumpage from these sources is almost nil, and with the amount of possible error in the estimates of the pumpage rates and no criteria under steady-state conditions to measure the effect the pumpage had on the potentiometric surface, the pumpage from these sources was excluded. However, to insure that this assumption was correct, a computer run was made including the average weather irrigation rates; figure 28 shows the changes in head caused by the additional pumpage. The rates were obtained from Tibbals (written commun., 1981) and one modification was made to his data. His information had the drainage wells in Orlando accepting water from the lakes and recharging the Floridan aquifer. During September 1980, the lake levels were such that the amount of water entering the drainage wells was insignificant, so the amount of water recharging the Floridan aquifer was not simulated.

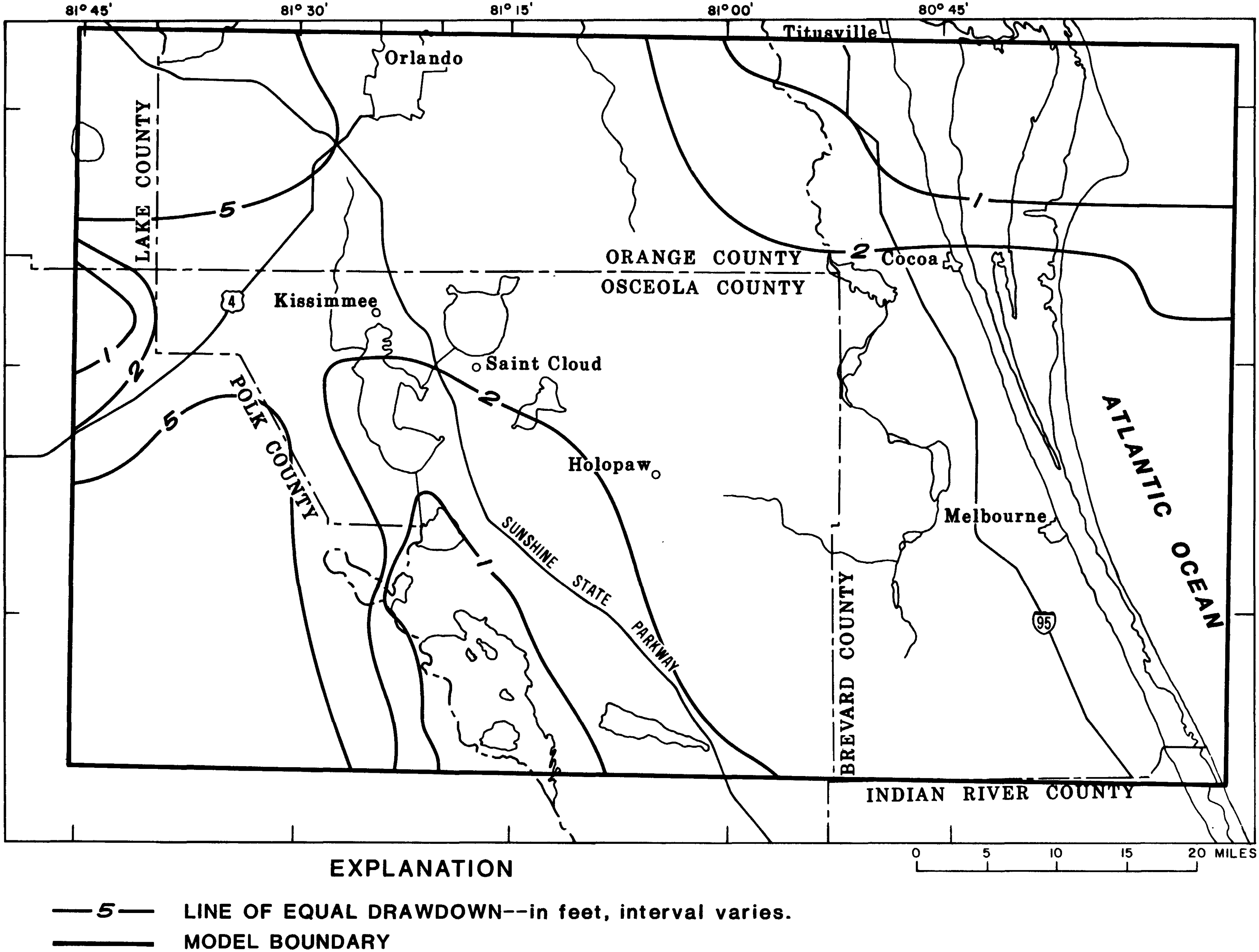


Figure 28.--Head change, in feet, for average-weather pumping from sources other than public supply (mainly irrigation).

Figure 28 shows that the maximum change was 5 feet in the western part of the study area, and that the effect within the area of probable development was about 2 feet. Therefore, excluding the pumpage from these sources has no severe effect upon the calibrated model due to the number and distribution of pumping centers, even though the combined pumpage rate for sources other than public supply was modeled as nearly 95 Mgal/d. It should be pointed out that, as an annual rate, about 45 to 50 Mgal/d would probably be better to use in a steady-state analysis for determining effects on the potentiometric surface because pumpage for irrigation is significant for only half the year, and this seasonal pumpage draws water from storage which is replaced during the wet part of the year.

Pumping Evaluation

The purpose of the study was to determine and describe the geohydrology in the area of Osceola, Orange, and Brevard Counties, and to develop a model of the aquifer system to evaluate various pumping schemes in which the pumped water would maintain a chloride concentration below 250 mg/L. Information is insufficient on the geology or the distribution of chloride concentrations with depth to allow prediction of the chloride concentration of water that would be pumped from a hypothetical well field. A general indication of the expected water quality can be estimated by superimposing the potentiometric surface for a proposed pumping scheme under equilibrium conditions over the distribution of chloride concentrations. From the potentiometric surface and the calculated cone of depression, the "area of diversion" (Brown, 1963b) can be defined for a pumping scheme. The amount of area that extends into a zone of poorer water quality can then be used to compare different schemes that derive water from areas where chloride concentrations are less than 250 mg/L.

The area of diversion around a well or well field is the area from which the pumping center actually draws its water. In a ground-water system with natural head gradients, the area of diversion is not coincident with the cone of depression caused by pumping. The limits of the area of diversion downgradient and to the sides are defined by a ground-water divide that is caused by the pumping and is in relative close proximity to the pumping center. The limit for the area upgradient is the natural ground-water divide in the recharge area for the aquifer and can be difficult to define depending on the location of the pumping center. The upgradient extent of the areas of diversion in this study was arbitrarily drawn to the 80-foot contour on each potentiometric surface. Most important are the downgradient limits. Because the initial quality of water is based on the water flowing from the recharge area, any declines in quality will be from water derived downgradient of the well fields.

This analysis only considered lateral movement of water. Little is known about the areal vertical distribution of chloride concentration, so analysis of upconing of saline water from depth was not attempted. The only data within the study area that are directly related to potential for upconing are for a deep multizoned observation well in the Cocoa well field; these data do not indicate significant effects of upconing. The authors generally feel that contamination of a well field in central Osceola County is much more likely to occur by lateral, rather than upward, migration of high chloride water as long as supply-well depth is restricted to the upper 500 feet of the Floridan aquifer.

Seven pumping schemes with simulated pumping from the upper Floridan were examined using the model--two schemes with withdrawals of 22 and 30 Mgal/d for a hypothetical well field west of Holopaw; one scheme that increased the Cocoa well field by 13 Mgal/d; two schemes for combinations of Holopaw and Cocoa that yielded an additional 35 and 50 Mgal/d; plus two schemes of 5 and 20 Mgal/d from a hypothetical well field in southwest Brevard County. All schemes included the estimated 1978 pumpage as used in the calibration.

Table 5 lists the amount of water supplied by the sources available in the model. In table 5, induced recharge represents change in the amount of water flowing through the upper confining layer as a result of the lowered heads in the Floridan aquifer. For all model runs, the rate of water moving through the upper confining layer increased a maximum of 1 inch per year for one mi^2 block. The water supplied by this source would be obtained by a decrease in discharge from the surficial aquifer--that is, either a reduction in evapotranspiration or in runoff to streams.

Table 5.--Source and quantity of water supplied to pumpage for the model experiments

Experiment	Quantity	Layer 1 boundaries (Mgal/d)		Layer 2 boundaries (Mgal/d)			Capture of water leaking to the Kissimmee River (Mgal/d)	Induced recharge (increase in downward leakage due to pumping)(Mgal/d)
		North	West	North	West	South		
1	22.0	0.5	0	0.9	0	1.6	11.0	8.0
2	30.0	.7	0	1.3	0	2.3	12.9	12.8
3	13.0	.8	0	1.6	0	.5	2.6	7.5
4	35.0	1.0	0	2.0	0	2.5	14.9	14.6
5	50.0	1.8	0	3.8	0	3.2	16.2	25.0
6	5.0	.1	0	.1	0	1.6	1.3	1.9
7	20.0	.3	0	.3	0	7.4	4.5	7.5

For the pumping experiments, the southern border was changed from a no-flow to a head-controlled flux boundary, and the flow defined during calibration from the constant heads was input as a constant flux. These changes were made because the two experiments that tested the southwest corner of Brevard County would cause significant drawdown past the border. Without the change, the constant heads could yield an inordinate amount of water while the no-flow section would produce an inordinate amount of drawdown. The head-controlled flux boundary was designed to yield zero flow under the calibrated conditions. The head at the flux boundary was set equal to the head in the last adjacent block within the model, so there was a zero gradient between the boundary and model for calibrated conditions. Flow into the model occurred only when pumping stresses lowered the original heads along the southern border. The simulated aquifer would be extended 10 miles with this boundary, assuming the transmissivity values remain constant in the aquifer.

A major source of water for the pumping schemes was the reach of the Kissimmee River starting with Lake Tohopekaliga and continuing downstream. The maximum percentage supplied by the river was 50 percent for experiment 1, and the minimum was 20 percent for experiment 3. Nowhere in the seven experiments did the head gradients between the aquifer and the river reverse. Thus, streamflow was not being induced into the aquifer, but water in the Floridan aquifer was being diverted to the pumping centers instead of being discharged into the river.

Experiment 1 simulated pumping 22 Mgal/d from 4 grid blocks west of Holopaw (fig. 29). Each square pumped an equal amount, and the drawdown for each block was 12 feet which mathematically relates to a radius of approximately 1,000 feet for a side length of 5,280 feet. (The drawdowns do not represent any particular well field design; the actual drawdown as a result of a well or wells located in the center of the block will be greater than the amount presented.) Figure 29 shows the area of diversion for both the Cocoa and Holopaw well fields because the area of diversion for Cocoa may be altered by drawdown from the Holopaw well field. The experiment shows that the areas of diversion do not intersect an area of poorer quality of water (fig. 29). The sources of water supplied for experiment 1 are 14 percent from the boundaries, 50 percent from the Kissimmee River, and 36 percent from induced recharge.

Experiment 2 simulated pumping 30 Mgal/d from the area west of Holopaw using the configuration in experiment 1. The drawdown around each center of pumping was 16 feet at an approximate radius of 1,000 feet. Figure 30 shows the areas of diversion for the Cocoa and Holopaw well fields. Pumping the additional 8 Mgal/d caused the area of diversion to expand into the zone of water south of Holopaw where chloride concentrations range from 200 to 260 mg/L. However, the area of poor quality intercepted is relatively small and water from the poor quality area should not affect significantly the quality pumped from the simulated well field. The amount of water supplied by the sources are 14 percent by the boundaries, 43 percent by the river, and 43 percent by induced recharge (table 5).

Experiment 3 simulated an increase in the Cocoa well field pumping rate from 15 to 28 Mgal/d. The rate for each pumping block in the east-west direction was doubled (fig. 31). One block to the southeast was held constant because of the initial problem of high chloride concentrations that occurred in the eastern section of the well field (Tibbals and Frazee, 1976). Figure 31 shows that the area of diversion contacts but does not overlap the 250 to 500 mg/L chloride areas. Drawdown for the pumping blocks ranged from 8 to 10 feet. The amounts of water supplied by sources are 22 percent from the boundaries, 20 percent from the Kissimmee River, and 58 percent from induced recharge.

Experiment 4 simulated an increase of 5 Mgal/d at Cocoa plus pumping 30 Mgal/d at the site west of Holopaw. The two westernmost pumping blocks in the Cocoa well field were increased 2.5 Mgal/d each for a total of 20 Mgal/d, and the Holopaw well field was simulated as pumping 30 Mgal/d. Drawdown in the Cocoa well field was increased 6 to 8 feet at a radius of 1,000 feet, and the drawdown at the pumping blocks for the Holopaw well field was 17 feet. Figure 32 shows the resulting potentiometric surface and the areas of diversion. In comparing experiments 2 and 4, pumping the

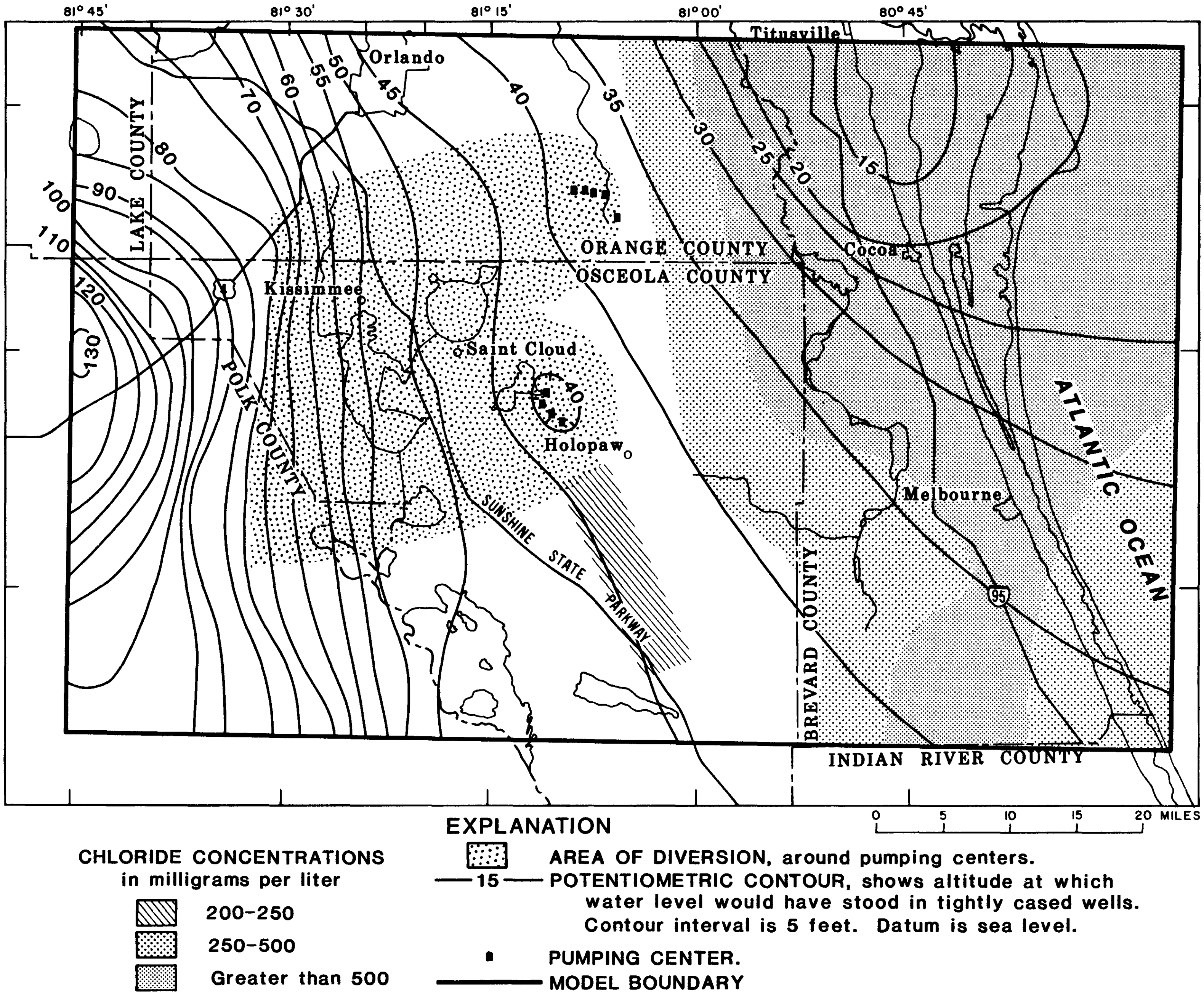


Figure 29.--Potentiometric surface of the upper limestone layer at a new equilibrium for experiment 1, Cocoa pumping 15 million gallons per day and Holopaw pumping 22 million gallons per day, and areas of diversion around the pumping centers.

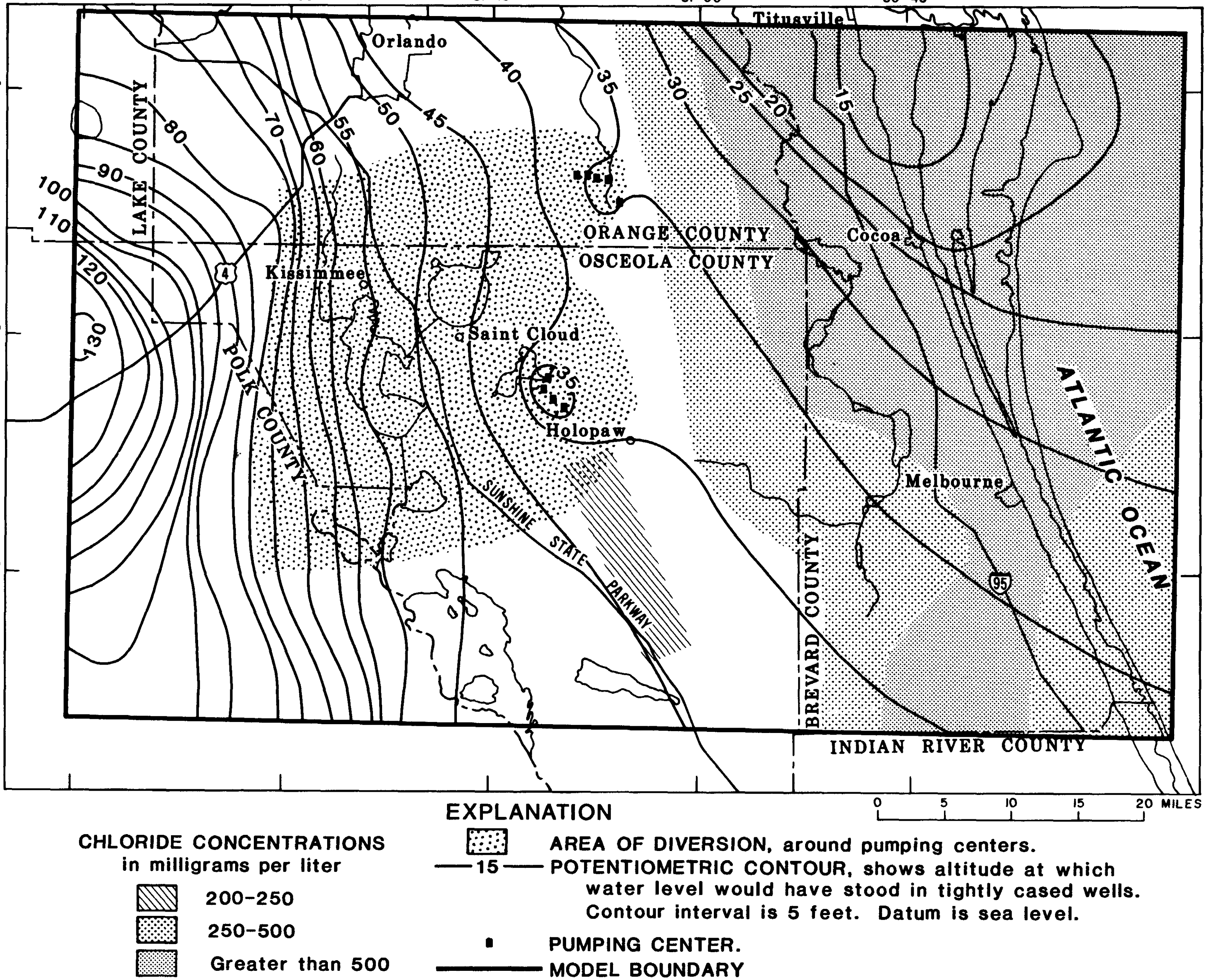


Figure 30.--Potentiometric surface of the upper limestone layer at a new equilibrium for experiment 2, Cocoa pumping 15 million gallons per day and Holopaw pumping 30 million gallons per day, and areas of diversion around the pumping centers.

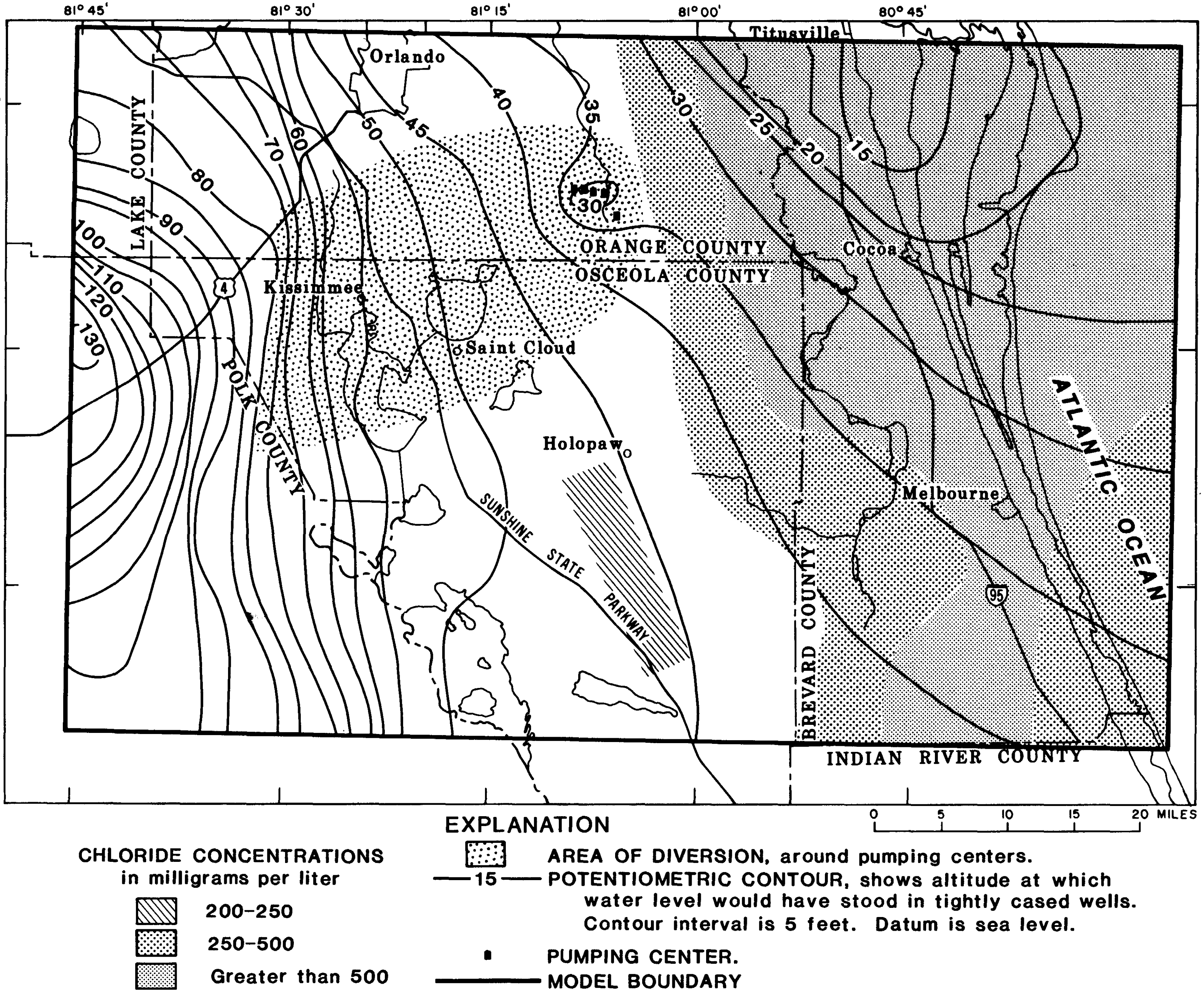


Figure 31.--Potentiometric surface of the upper limestone layer at a new equilibrium for experiment 3, Cocoa pumping 28 million gallons per day, and the area of diversion around the pumping center.

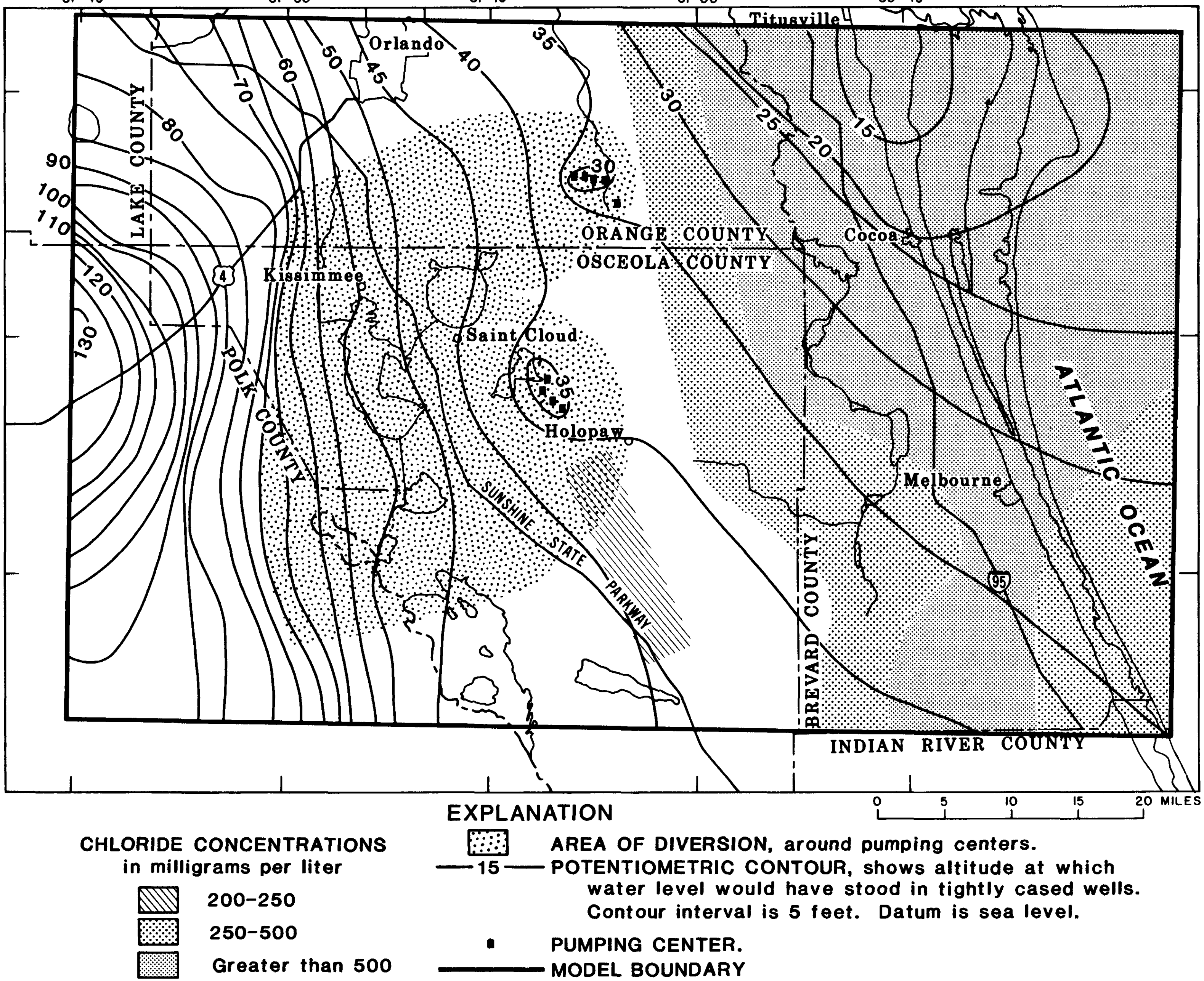


Figure 32.--Potentiometric surface of the upper limestone layer at a new equilibrium for experiment 4, Cocoa pumping 20 million gallons per day and Holopaw pumping 30 million gallons per day, and the areas of diversion around the pumping centers.

extra 5 Mgal/d at Cocoa caused one extra foot of drawdown at the Holopaw well field. The results are fairly similar for the two experiments except that, in experiment 4, the Cocoa well field is surrounded by a 30-foot potentiometric contour, and the boundary of the area of diversion contacts the area of 250 mg/L or greater chloride concentration. The amounts of water derived from the sources (table 5) are 15 percent from the boundaries, 42 percent from the river, and 43 percent from induced recharge.

Experiment 5 simulated the largest withdrawal--an increase of 20 Mgal/d (total of 35 Mgal/d) at the Cocoa well field that included two new pumping blocks plus Holopaw pumping at a rate of 30 Mgal/d. Drawdowns for the pumping blocks were about 14 feet for the Cocoa well field and 18 feet for the Holopaw well field. The area of diversion for the Holopaw well field (fig. 33) remained practically the same as that in experiment 4 (fig. 32), but the area of diversion for the Cocoa well field moved slightly into the area of poorer water quality. Production of water with this pumping scheme approaches potentially unacceptable effects, but mixing of waters could still render this scheme acceptable. The amounts of water derived from the sources (table 5) are 18 percent from the boundaries, 32 percent from the river, and 50 percent from induced recharge.

The water-supply potential of the southwest corner of Brevard County was tested because chloride concentrations are less than 250 mg/L and it would be preferable to locate a well field within the county's boundaries. Caution should be used, however, in evaluating test results because the model was not designed to test southwest Brevard. Although the analysis will give an indication of the ground-water potential, the pumping is too close to the border of the model for the results to be absolutely reliable. Variations of transmissivity or water quality outside the modeled area could drastically change the results described in the following two experiments.

Experiment 6 simulated 5 Mgal/d being pumped from one block in southwest Brevard County (fig. 34). Drawdown for the pumping block was 6 feet. Figure 30 shows the potentiometric surface and the area of diversion. The area of diversion contacts the boundary line for the 250 mg/L or greater chloride concentration. Because the water at the location of the pumping block has a chloride concentration greater than 200, 5 Mgal/d is the approximate limit for production at this site. The amounts of water from the sources (table 5) are 35 percent from the boundaries (most of which comes from the southern boundary), 26 percent from the river, and 39 percent from induced recharge.

Experiment 7 simulated three north-south pumping centers that pumped at a rate of 20 Mgal/d. Drawdown for the pumping centers was 15 feet. The area of diversion for this pumping scheme incorporates a substantial area of poor water quality (fig. 35) that crosses into the zone where chloride concentrations are greater than 500 mg/L. This pumping scheme would probably not succeed in maintaining chloride concentrations of less than 250 mg/L. The amounts of water from the sources are 40 percent from the boundaries, 23 percent from the river, and 37 percent from induced recharge.

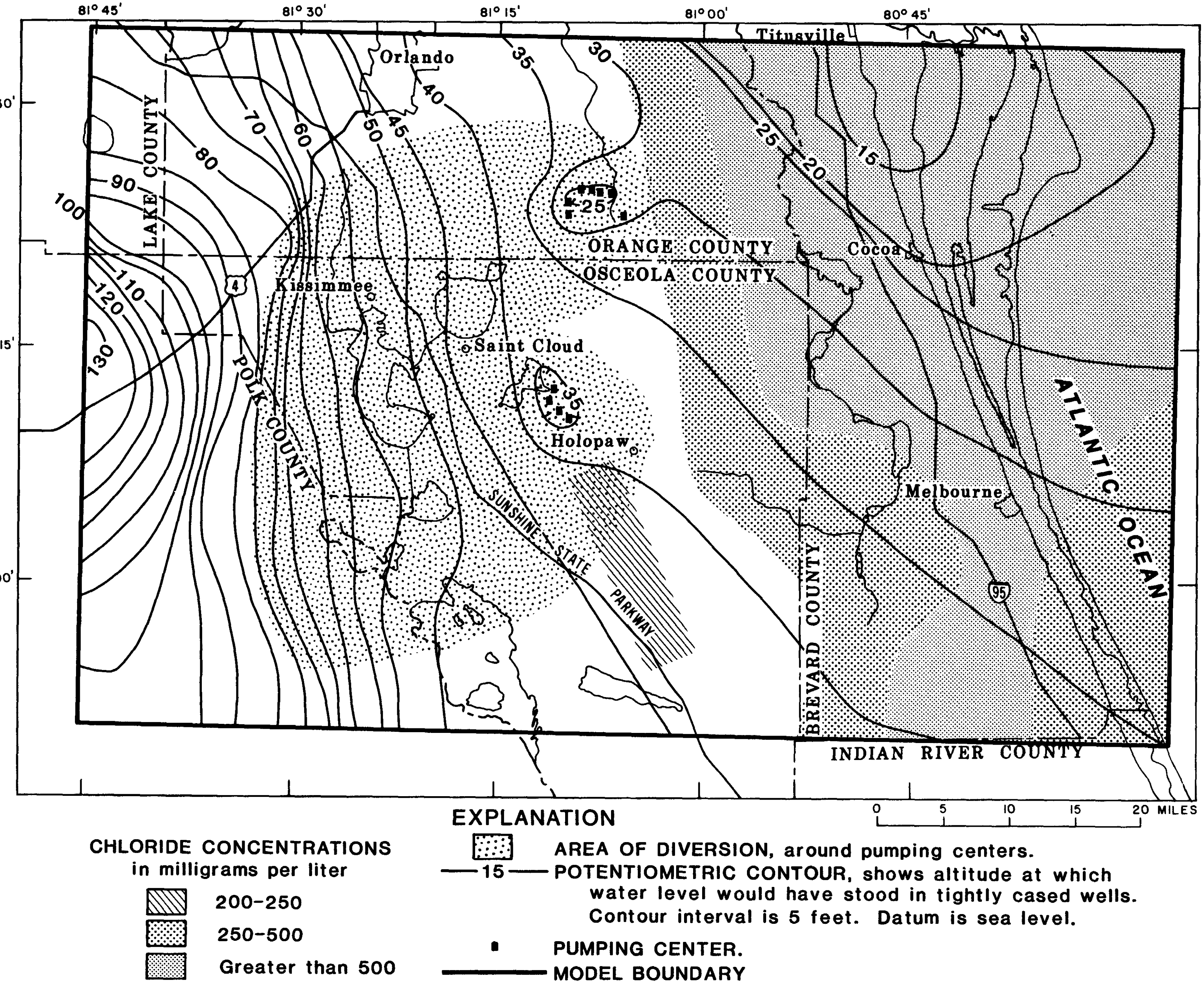


Figure 33.--Potentiometric surface of the upper limestone layer at a new equilibrium for experiment 5, Cocoa pumping 35 million gallons per day and Holopaw pumping 30 million gallons per day, and the areas of diversion around the pumping centers.

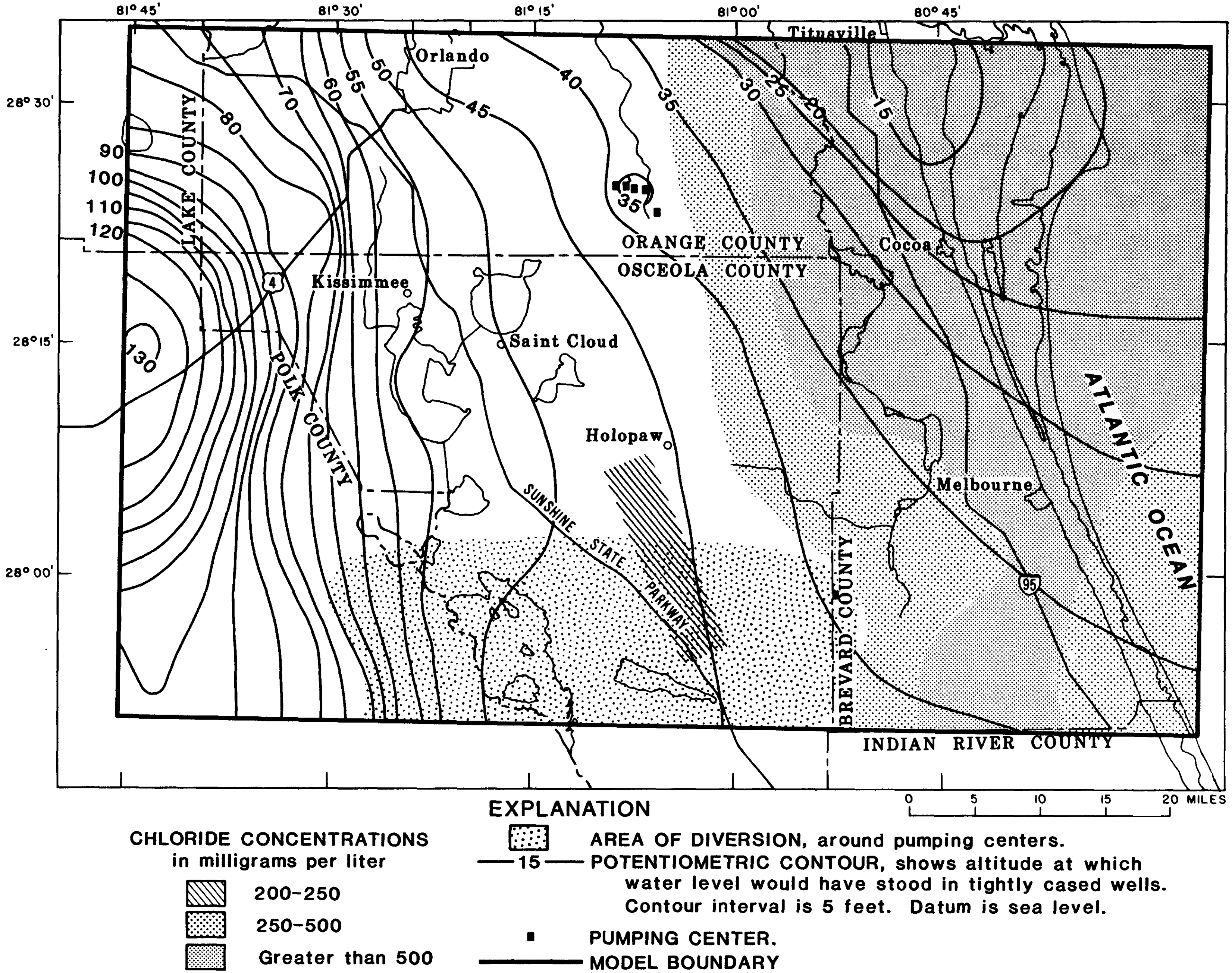


Figure 34.--Potentiometric surface of the upper limestone layer at a new equilibrium for experiment 6, southwest Brevard pumping 5 million gallons per day, and the area of diversion around the pumping center.

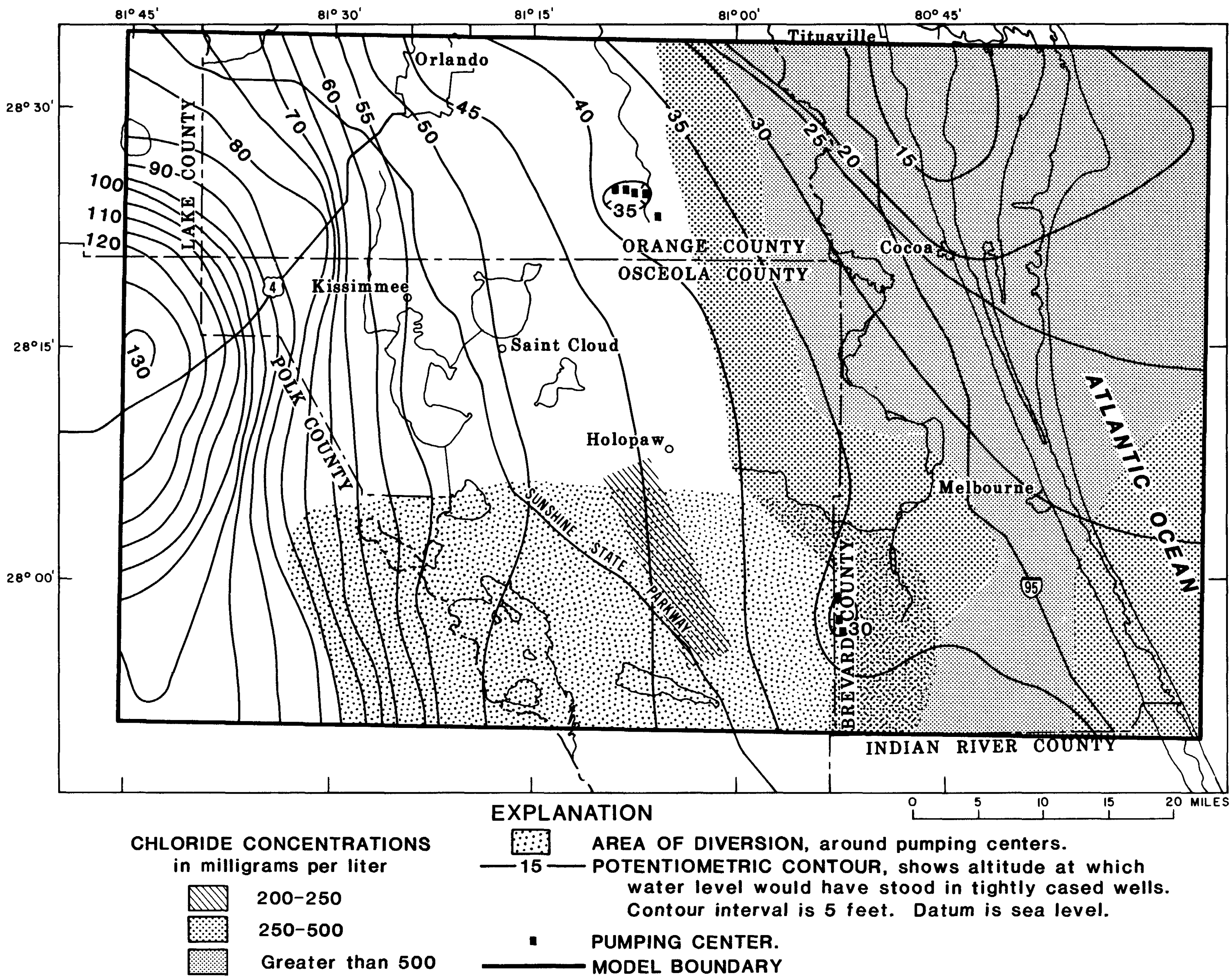


Figure 35.--Potentiometric surface of the upper limestone layer at a new equilibrium for experiment 7, southwest Brevard pumping 20 million gallons per day, and the area of diversion around the pumping center.

SUMMARY AND CONCLUSIONS

Population growth predictions indicate south Brevard County will need a water supply three times larger than Lake Washington, their present supply, can provide. This study examined, as one alternative, obtaining the needed water from well fields in the Floridan aquifer. High chloride concentrations in Brevard County necessitate locating a well field to the west of the county.

Successful completion of the study objectives required defining the geohydrology in Osceola County. Data were collected to define the ground-water system, the hydraulic parameters of the units, and the variance in chloride concentrations. The ground-water system can be divided into three units: (1) a surficial aquifer, comprised of unconsolidated sand, shell layers, and clay that contains the water table; (2) a confining layer of low permeability materials; and (3) the Floridan aquifer, comprised of limestones and dolomitic limestones. The thicknesses of the upper confining layer and the top of the Floridan aquifer were mapped with the aid of logs, both geophysical and lithological. Two aquifer tests were performed on zones in the surficial aquifer to determine hydraulic properties of aquifer materials in the surficial aquifer and vertical hydraulic conductivity of the underlying confining materials. Nineteen specific capacity tests were performed on Floridan wells to estimate transmissivity for that aquifer. Water samples were analyzed for chloride concentrations and, variations in concentrations were mapped. Chloride data indicate that a well field located west of Holopaw in north-central Osceola County would likely provide a dependable supply of potable water. The distribution of data prevented mapping chloride variations with depth.

Most ground water in the study area is derived from rainfall. The flow pattern of ground water in the Floridan aquifer for the study area is eastward from the potentiometric surface high in Polk County. The main drain of the aquifer (lowest point on the potentiometric surface) is the Indian River in northern Brevard County. Most of Brevard County is a discharge area for the Floridan aquifer where the potentiometric surface is above the land surface.

A digital model was constructed to help define the ground-water system and to determine the feasibility of using ground water as a source for south Brevard County's water supply. The model was calibrated to conditions in September 1980, and 60 percent of 114 points of measurement were calculated to within 2 feet of the actual measurement, and only two measurements (6 and 8 feet) were greater than 5 feet of the calculated values. Sensitivity analysis showed the vertical hydraulic conductivity of the confining layer and the connection between the Kissimmee River and the Floridan aquifer to be the most sensitive parameters. Seven pumping schemes of the aquifer system were analyzed with a digital model--an increase in production at the Cocoa well field in Orange County, establishment of a new well field west of Holopaw in Osceola County, and a combination of pumping from both well fields. The five pumping schemes tested outside Brevard County succeeded in producing water of suitable quality, based on the analysis used. The scheme that produced the greatest quantity of water increased the yield of the Cocoa well field by 20 Mgal/d. Considering the high chloride concentration problem in the eastern part of the Cocoa well field, this scheme could fail if the head reduction allowed high chloride water to migrate to the new pumping center. The chloride problem cannot be evaluated with the available data. With any planned increase of pumping rates for the Cocoa well field, it would be desirable to install observation wells east of the pumping center and at depth to monitor any trend of increasing chloride concentration.

Several of the Holopaw area well field pumping schemes intercept the area of high chlorides south of Holopaw in Osceola County. The area is poorly defined and its precise effect on water quality in the hypothetical well field cannot be evaluated, but it appears that the high chlorides are contained in a lower zone within the Floridan aquifer. However, the percentage of high-chloride zones included in the area of diversion is relatively small, and the effect on a well field at the simulated site likely would be slight. The transmissivity of the upper part of the Floridan aquifer increases to the north and west of the Holopaw area. If production wells can be drilled to depths that do not interconnect with the lower zone of poorer quality of water, there may be little or no contribution of water from this zone. Only site specific testing can determine whether enough water can be pumped from the upper zones of the Floridan aquifer in the hypothetical well field area west of Holopaw.

Two pumping schemes were simulated to determine the potential of a well field in the southwest corner of Brevard County. The results showed that 5 Mgal/d was about the maximum available and that a higher rate would probably produce nonpotable water.

The major results of this study show that an additional 50 Mgal/d of water may be produced over the present rate from an expansion of the Cocoa well field and with construction of a new well field west of Holopaw. A well field west of Holopaw, based on the model, should produce at least 30 Mgal/d.

If the ground-water alternative is chosen for the future supply, it would be desirable to install an observation well network to monitor head changes, chloride concentration trends east of the pumping centers, and chloride concentration trends in zones below the pumped zone.

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